IMPACT OF QUALITY AND RELIABILITY OF IRRIGATION ON FIELD AND FARM LEVEL WATER PRODUCTIVITY OF CROPS

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Abstract

This paper examines the impact of quality and reliability of irrigation on water productivity of individual crops and cropping system in the farm through comparison of crops watered by different types of irrigation systems such as canal irrigation; well irrigation and conjunctive use. Then it analyzes the actual factors that drive differential productivity, and which change due to change in quality and reliability regime of irrigation. The study area is Bist Doab area in Punjab and the analysis was carried out for two agro-climatic regions, both semi-arid, one having medium to high rainfall and the other having low to medium rainfall. The first location (Changarwan) is predominantly canal and well irrigated, whereas the second location (Skohpur) has well irrigation and conjunctive use.

The analysis involved working out an index called "irrigation quality index" for different types of irrigation systems, and then compares water productivity of individual crops vis-à-vis estimated values of this index, for each location. The crop water productivity parameters analyzed are: physical productivity of water in kg/m^3; and water productivity in economic terms.

Overall, the irrigation quality index was higher for: well irrigated fields as compared to canal irrigated fields and fields irrigated by both wells and canals in Skohpur; and canal irrigated fields for most crops in Changarwan. Comparison of irrigation water quality index estimated for major crops under different sources of irrigation vis-à-vis the water productivity of the respective crops show that differential reliability has an impact on economic productivity of water (Rs/m^3). The fields, which received irrigation water of higher quality and reliability got higher water productivity in rupee terms. However, the impact of differential quality and reliability was not visible on physical productivity of water for fodder crops.

Contrary to the belief that higher quality and reliability of irrigation would result in better yields, the fields, which were receiving poor quality irrigation gave higher yields. This was primarily due to the high nutrient load which canal water contained that increased the yield of those crops. Fodder crops also gave higher yields under less reliable irrigation water supply. Hence, one can conclude that improved quality and reliability of irrigation would help enhance the water productivity in crop production.

1. INTRODUCTION

The criteria for evaluating irrigation systems have undergone major modifications in the last 30 years from the classical irrigation efficiencies to measuring performance using a variety of indicators (see Bastiaanssen and Bos, 2001), taking into account productivity of irrigation water with accent on yield (Perry and Narayanamurthy, 1998; Sarwar and Perry, 2002; Seckler *et al*., 2003), and revenue enhancement per unit of depleted water (Barker *et al*., 2003); and equity in water distribution (Svendson and Small, 1990). As scarcity of irrigation water is becoming evident in many regions and demand for water increasing from other competing sectors of use (Perry and Narayanamurthy, 2001), there is a need to assess the quality of irrigation services in relation to productivity of water rather than land (Sarwar and Perry, 2002). This means, the criteria for assessing system-wide irrigation management strategies adopted by irrigation agencies also needs to be revisited. In other words, the factors that need to be taken into account for assessing the quality of irrigation also needs to change, the reason being the factors that influence yield are not exactly same as those, which influence water productivity.

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Crop water productivity can be defined either as the yield per unit of water depleted in crop production or applied for crop production; or the net return from crop production per unit of depleted water or water applied (Kijne *et al*., 2003). Hence, the key drivers of change in water productivity are: amount of water depleted in crop production as it changes both the numerator and denominator of productivity parameters; and all crop inputs including crop variety, fertilizer and pesticide dosage and labour as they determine the crop yields and net returns, which change the numerator of water productivity. Now let us see how the reliability and quality of irrigation affects these drivers; and therefore water productivity. It is an established fact that while crop yield or biomass production increases in proportion to increase in transpiration, at higher doses, irrigation does not result in beneficial transpiration, but non-beneficial evaporation. This way, increased evapo-transpiration does not result in proportional increase in yield of crops (Vaux and Pruitt, 1983). Non-recoverable deep percolation is another non-beneficial component of the total water depleted from crops during irrigation (Allen *et al*., 1998). This also increases at higher dosage of irrigation.

It is very likely that with greater quality and reliability of irrigation, the farmers are able to provide optimum dosage of irrigation to the crop, controlling the non-beneficial evaporation, and non-recoverable deep percolation. The result will be that the consumed fraction will remain low, and the fraction of beneficial evapo-transpiration within the consumed fraction (CF) (depleted water) will remain high[2]. It is also possible that with high reliability of available supplies, even under scarcity of irrigation water, the farmers can adjust their sowing time such that they are able to provide critical watering, thereby obtaining high yield responses. Both result in higher water productivity. Further, if more reliable irrigation water is available, farmers would be encouraged to use high yielding varieties, and apply adequate amount of fertilizers and pesticides to their crops, resulting in better crop yields. Hence, the overall outcome of improved quality and reliability of irrigation would be higher water productivity.

The purpose of the paper is to: i] develop quantitative criteria for measuring the quality and reliability of irrigation water that capture the complex physical variables relating to irrigation and affecting crop water productivity; ii] assess the impact of quality and reliability of irrigation on water productivity in agriculture, through analysis of individual crops; and then, iii] analyze the factors that cause differential water productivity, and which change due to change in quality and reliability regime.

2. REVIEW OF LITERATURE ON ANALYZING THE IMPACT OF IRRIGATION MANAGEMENT STRATEGIES

The recent past has seen an increase in enthusiasm among irrigation researchers worldwide, in trying to develop indicators for measuring performance of irrigation systems and also to assess the impact of different irrigation management strategies on crop yields and productivity of land and water quantitatively, in view of the growing shortage of irrigation water, and the competing demands for water from other sectors. Four main strategies, which were examined are: providing deficit irrigation; improving the timeliness of irrigation; precision irrigation; and improving the quality and reliability of irrigation. One of the motivating factors behind this is to identify the best strategy for improving the performance of irrigation systems, given its potential as a powerful tool to manage the demand for water in agriculture.

Svendson and Small (1990) analyzed farmers' perspective of irrigation system performance. They found that the way farmers evaluate performance of irrigation systems mainly concern the outcomes and impacts of irrigation systems rather than the processes involved in managing irrigation such as staffing policies of the agency, pattern of communication and nature of farmers' participation in water users associations. According to them, the ten important measures that farmers use to assess irrigation system performance are: depth related measures viz., adequacy, equity and timeliness; farm management related measures such as tractability, convenience and predictability; and water quality related measures viz., temperature, sediment content, nutrient content, toxics and pathogens. How these criteria can be converted into normative indicators for analyzing irrigation system performance, or even strategies for improving the same were not addressed.

[2]See Allen et al., (1998) for detailed discussion on various components of the applied water, such as consumed water, consumed fraction, beneficial transpiration, non-beneficial evaporation from the soil and non-recoverable deep percolation.

Bastiaanssen and Bos (1999) argued that a new generation of irrigation performance indicators such as adequacy, equity and productivity could be quantified using remote sensing data, based on previous work by several scholars such as Azzali and Menenti (1987), Bastiaanssen (1994), Menenti *et al*. (1989), Moran (1994), Roerink *et al*. (1997). For instance, Menenti *et al*. (1989) measured equity in irrigation water distribution by evaluating the actual flow per unit irrigated area, at different spatial scales, in which the irrigated area was measured using satellite data. Moran (1994) used vegetation index and surface temperature to assess the adequacy. Bastiaanssen (1994) expressed adequacy in irrigation as a ratio of the total energy consumed by the crop in the form of ET and the total energy available for ET, and computed it from surface energy balance. He argued that equity in irrigation performance could be evaluated by taking a digital overlay of the SEB, with administrative boundaries and calculating the coefficient of variation across space. Roerink *et al*. (1997) extended the ET fraction approach used by Bastiaanssen (1994) and calculated coefficient of variation of actual ET over total water supplied to quantify productivity.

There were lots of anecdotal and research based evidences from around the world showing differential productivity gains in well irrigation over canal irrigation vis-à-vis yield and water productivity, and this gain has been attributed to virtues of well irrigation over canal irrigation such as timeliness, and greater quality in terms of adequateness and control over water delivery (Llamas, 2000; Chakravorthy and Umetsu, 2004). Some empirical studies showed positive impact of timeliness of irrigation on paddy yields in canal command areas (Meinzen-Dick, 1995). Whereas some studies showed positive differential yield and net returns from crop production in diesel engine irrigated crops over electric-pump irrigated crops (Kumar and Patel, 1995), with the difference being attributed to access to and control over irrigation possible with diesel engine operated wells, i.e., the ability of the farmers to irrigate the crop as and when required or better “timeliness”.

Studies in Pakistan Punjab showed greater yields obtained by farmers who use conjunctive irrigation in canal command areas as compared to those who use only canal water for their wheat and rice crop (Hussain *et al*., 2003). A study by Sarwar and Perry (2002) in Indus plains of Pakistan, which simulated crop growth and ET under different irrigation schedules, using SWAP (Soil-Water-Atmosphere-Plant) model showed that it is possible to enhance crop water productivity through deficit irrigation. The study showed 47% higher crop water productivity under deficit irrigation conditions as compared to unrestricted irrigation supply condition, which led to the conclusion that while applying water to meet the exact crop water requirement would be the right strategy under situations of plentiful water, in situations of scarcity, restricted water supply would be the strategy to maximize productivity of water. But, whether irrigation is in deficit regime, or in water surplus regime, is highly crop specific, and their actual impacts on crop production cannot be assessed realistically, unless the farmers’ response in terms of crop choices are also modeled.

According to another analysis by Perry and Narayanamurthy (1998), rationing irrigation to make it available during critical stages, which correspond to points where the yield sensitivity to ET is high, is a useful strategy in enhancing crop yields. However, there are practical problems in assessing quality of irrigation in terms of water availability during critical stages, and then applying it to devise appropriate water delivery policy for an irrigation scheme. First: the sowing time for crops varies significantly across farmers within the same irrigation command thereby the timing for critical watering changes across farmers. Second: farmers in many irrigation systems in Asia grow multiple crops with critical stage with respect to “growth response to ET” differing widely. More over, the quality of irrigation available from an irrigation system cannot be assessed in relation to water availability during critical stage alone.

In a nutshell, review of available irrigation literature shows that the studies cover either analysis of different indicators for analyzing irrigation system performance from different perspectives - farmers and irrigation agencies; use of different scientific methodologies to assess the performance of irrigation schemes in terms of crop yields or crop growth; or different approaches to improve the performance of irrigation systems in terms of their outcomes, under a set of conditions existing in the field vis-à-vis crops and climate; or merely qualitatively analyze the impact of quality of irrigation on crop yields. But, it is important to note here that the real field outcomes of introducing irrigation management strategies suggested by such crop growth-based econometric models (see for instance, Perry and Narayanamurthy, 2001) would deviate from the model predictions. This is because such models fail to take into account the farmers’ decision making variables with regard to crop choices under different irrigation water supply regimes. Most of the studies assess productivity in relation to land.

Such studies, therefore, leave major information gaps about the governing parameters in irrigation management that need to be manipulated for improving the performance and that are critical for working out operational policies for irrigation management, and their expected outcomes. There is hardly any empirical research that attempts to develop quantitative criteria, which uses measurable physical indicators, for assessing the quality and reliability of irrigation and which captures the complex variables such as timeliness of irrigation, physical access to irrigation water source, water delivery rates and control over water delivery[3]. Such quantitative measures are important for working out operational policies for irrigation management.

Further, very little is known about how improved quality and reliability of irrigation cause differential productivity, and the extent to which they contribute. What is best known is the physical processes involved in plant growth, and how that changes with irrigation. But, what is needed is the real life impacts of different irrigation management interventions like improving "quality and reliability" of irrigation on productivity of water.

3. THE STUDY OBJECTIVES AND METHODOLOGY

3.1 Study Location

In Bist Doab area of Punjab, the climate varies from semi arid to hot, sub-humid from south west to north east (Hira and Khera, 2000). The Bist Doab area provides a unique opportunity to analyze the impact of reliability of irrigation on crop yields and water productivity. The reason is the presence of farmers using canal water, groundwater and both in the same location with similar agro-climate. Also, incidentally, there are pockets where reliability of canal irrigation is quite high, against locations which are traditionally known for poor quality canal irrigation. This can help overcome the problem of wrongly attributing differential productivity to a particular source of irrigation.

One of the locations (Changarwan village) chosen for the study in Hoshiarpur district, which receives adequate amount of canal water from Shah Neher canal. Very few farmers have wells, which are located outside the command. But, farmers who receive canal water do not practice well irrigation. The area, which is part of the sub-mountainous region of Punjab, receives nearly 900mm of rainfall, and is hot and sub-humid. The second location (Skohpur village) located in Nawanshehr district is well known for intensive well irrigation, and the canal water supply is generally poor, except in very good rainfall years. The area receives a mean annual rainfall of approximately 450 mm (source: based on Hira and Khera, 2000). Most of the farmers who receive canal water also practice well irrigation, at least for some crops.

3.2 Objectives

The objective of this paper is to analyze the impact of quality and reliability of irrigation on field level water productivity of crops. This is done by comparing the physical productivity of water for individual crops; and water productivity in economic terms under different types of irrigation systems with differential quality and reliability vis-à-vis the irrigation quality and reliability index for these systems.

3.3 Methodology[4], Sampling, Analytical Procedures

The quality and reliability of irrigation influences water productivity in many different ways. First, good quality and reliable irrigation services provide farmers with the opportunity of optimizing the dosage of irrigation, which can help prevent non-beneficial evaporation of soil moisture from the field during the crop development stages and residual moisture in the soil after the crop harvest thereby bringing the depleted water close to beneficial ET. Reliable and quality irrigation would motivate farmers to use fertilizers adequately, use high yield-

[3] This does not ignore the fact that several scholars had highlighted the need for improving the timeliness or irrigation on crop yields (Meinzen-Dick, 1995); providing watering at critical stages of crop growth (Perry and Narayanamurthy, 1998); and deficit irrigation under situations of water scarcity as crucial factors in enhancing productivity (Sarwar and Perry, 2002)

[4] This part draws heavily on the proposal titled "Analyzing the Trade offs in Maximizing Farming System and Regional Level Water Productivity" prepared by M. Dinesh Kumar for submission to the Department of Environmental Sciences, Wageningen University and Research Centre, Wageningen, the Netherlands.

ing seed varieties, invest in agronomic practices and also go for high-valued crops that involve more risk. This would positively affect yield. Since, differential input costs need to be factored in the productivity analysis, combined physical and economic productivity of water also need to be compared. Further, since cropping pattern might change from one source to another, overall net water productivity (Rs/m^3), including all the crops needs to be compared for understanding the real impact (Kumar, 2005).

Since there are perceptible differences in the quality and reliability of irrigation between canal irrigation and well irrigation and also between well irrigation and conjunctive use, the impact of reliability and quality on water productivity can be compared by comparing field level water productivity of depleted water for the same crop for these different sources (both in Kg/m^3 of applied water and Rs/m^3 of applied water). It is also important to quantify the quality and reliability of irrigation using certain realistic criteria based on physically measurable indicators. Then the productivity values for different sources will be compared against the estimated values of quality and reliability of the source.

The sample size for Changarwan village is 36, with 18 farmers using canal irrigation and 18 using well irrigation. In case of Skohpur village the sample size is 35, of which the farmers using well irrigation are 21 and those adopting conjunctive use are 14. Among these, there are 3 farmers who use only canal water supply for irrigating certain crops.

Primary data were collected from the sample farmers, in both the locations using real time monitoring. The data collected included: area under different irrigated crops; date of sowing and harvesting; the actual irrigation schedules including the timing and duration of each watering; crop outputs; the price of produce (price at which it is being procured by Food Corporation of India); the discharge of pumps; canal discharge rate.

4. ESTIMATING RELIABILITY AND QUALITY OF IRRIGATION

The differential quality and reliability of irrigation vis-à-vis a crop can be quantitatively estimated by using certain irrigation related physical parameters. They are: water control index; no. of irrigations; average duration per watering per unit cropped area; and maximum time duration between two waterings during the entire crop season. It is argued here that higher frequency improves the quality and reliability of irrigation. Also, the greater the duration of watering, the better would be the quality. On the contrary, greater the time gap between two watering for the same crop, poorer would be the quality of irrigation and greater would be the chances for crop damage due to water stress. Correct dosage of water could prevent leaching of fertilizers and other nutrients in the soil, thereby maintaining good growth.

Quality and reliability of irrigation for wells, canals and conjunctive use for a farmer, with respect to a given crop is assessed in terms of an irrigation quality index (δ_l) defined by

$$\delta_l = \frac{In_l Id_l \psi_l}{t_l} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ 7$$

$= [aq - bq_l^2]$ where, a=0.13 and b=0.0026

Whereis ψ_l the water control index for farmer l, In_i and Id_i are the number of irrigations and duration of irrigation (hr/acre), respectively, given by the sample farmer l for a crop; t_l is the maximum time duration between any two consecutive watering given by sample farmerfor l the crop in days. q_l is the rate of water delivery (l/s) for that farmer. It is assumed that a water delivery rate of 15 litres per second is best for the crop for which the index would be one and accordingly the values of coefficients a and were estimated. Further, the relationship between q and is assumed to be according to a convex curve. From the index obtained for each farmer in the sample, the mean values would be estimated and compared against the field level water productivity.

The way quality and reliability of irrigation is measured for a particular farm will have to be different from that for a particular field. This is because unlike in case of a field, in a farm, there would be many crops, each having different irrigation requirements, in terms of dosage and frequency. Therefore, assessing the quality and reliability of irrigation in relation to number of irrigations given, duration of irrigation and the maximum time duration between two waterings would be futile. For a farm, the parameters that matter when it comes to comparing reliability and quality between two sources of irrigation are: 1] the total time duration for which water is available at the farm gate for a given cropped area; 2] the time interval between two consecutive water deliveries at the farm gate; and, 3] the degree of control with which water can be applied in the field, which is determined by water control index.

Quality and reliability of irrigation with respects to all the crops in a farm can be assessed quantitatively as a function of the water control index (ψ); the average duration of water delivery per unit cropped area in the farm t_{farm} (hours per ha); and an inverse function of the cumulative time interval between water deliveries in the farm $t_{off-farm}$ (hours). The underlying premise in developing these criteria is that greater the duration of water delivery in the farm, greater would be the ability of the farmer to manage his irrigation. Larger the time interval between two water deliveries, lesser would be the reliability of the water supplies. Again, higher the water control index, greater would be the ability to provide optimum dosage of irrigation.

The detailed analytical procedure employed for estimating water productivity parameters is available in Kumar et al. (2008).

5. RESULTS AND DISCUSSION

5.1 Quality and Reliability of Irrigation Water Supplies for Different Irrigation Systems

Based on real time data on irrigation schedules, duration of irrigation and the water delivery of the source, the irrigation quality index was estimated for all the sources, viz., well irrigation, conjunctive irrigation and canal irrigation. The estimates for Changarwan are provided in Table 1 and that for Skohpur are provided in Table 2. As Table 1 shows, the IQ value is higher for well for all crops except paddy. This is understandable. In the case of wells, for a given crop, the number of irrigations was much higher. Also, the time gap between two consecutive watering was higher. In the case of paddy, the index is slightly higher for canal.

Table 1: Estimates of quality and reliability for canal irrigation and well irrigation at Changarwan (Zone I) for selected crops

Season	Crop	Source of Irrigation	Irrigation Quality Index
Kharif	Paddy	Well	2.66
		Canal	3.33
	Maize	Well	10.28
		Canal	0.65
	Bajra	Well	1.37
		Canal	0.25
Winter	Wheat	Well	2.26
		Canal	0.5
	Barseem	Well	0.44
		Canal	0.17

Source: author's own analysis based on primary data

In the case of Skohpur, there are three sources of irrigation, i.e., well, canal and conjunctive use. The IQ values are higher for well irrigation except for kharif bajra and maize. For maize, the IQ value is highest for conjunctive irrigation, and in the case of bajra the value is highest for canal.

Table 2: Estimates of Quality and Reliability for Well irrigation, Canal Irrigation and Conjunctive Use at Skohpur (Zone III) for selected crops

Season	Crop	Source of Irrigation	Irrigation Quality Index
Kharif	Paddy	Well	26.77
		Canal	13.51
		Conjunctive	28.16
	Maize	Well	2.63
		Canal	2.2
		Conjunctive	5.01
	Bajra	Well	1.44
		Canal	2.29
		Conjunctive	1.16
Winte	Wheat	Well	1.05
		Canal	0.87
		Conjunctive	1.25
	Barseem	Well	1.43
		Canal	1.17
		Conjunctive	0.32

Source: author's own estimates based on primary data

5.2 Water Productivity of Different Crops

The mean values of crop yields, and estimated mean values of irrigation dosage, and water productivity in physical and economic terms for the major crops viz., paddy, maize, bajra, wheat and barseem for well irrigated crops and canal irrigated crops are presented separately in Table 3 and Table 4. Comparing crop yields between irrigation sources show higher yield values for canal irrigated fields. The comparison shows the following: 1] the irrigation dosages are much higher for canal-irrigated fields for all the five crops; 2] physical productivity of water is higher for well-irrigated fields, for paddy, maize and wheat; and 3] the values of water productivity in economic terms are higher for well- irrigated fields for maize, bajra and wheat.

The irrigation dosages are excessive for fields, which are receiving canal water. But, still the yields are much higher for these fields when compared to well-irrigated fields in spite of the fact that the well irrigated fields are getting adequate quantities of water. One important reason for this differential yield is the chemical quality of irrigation water available through canals. As reported by the farmers in Changarwan village, the canal water, which comes from Bhakra irrigation scheme in Punjab-Himachal border is very rich in many minerals from the hilly catchments in the Shivalik hills. The continuous availability of this water for the past four decades had made the land receiving this water also very fertile. Hence, the nutrient regime in the soil is much higher in the canal irrigated fields.

The mean values of crop yields, mean values of estimated irrigation dosage, and mean values of estimated water productivity in physical and economic terms for the major crops irrigated by wells, canals and conjunctive method in Skohpur village are presented separately in Table 5, Table 6 and Table 7, respectively. Comparison across sources shows the following: 1] the depth of irrigation is highest for fields irrigated by canals, followed by conjunctive use, and lowest for wells for paddy and wheat; 2] the yield is higher for well irrigated fields for paddy, and barseem, whereas it is higher for canal irrigated fields in the case of maize; 3] the physical productivity of water is higher for well irrigated fields in the case of paddy, bajra, and wheat and highest for canal irrigated field in the case of maize. As regards water productivity in economic terms, values were higher for well-irrigated fields for all crops except bajra.

Table 3: Water Productivity Estimates of Different Crops under Well irrigation at Changarwan (Zone 1)

Well Irrigation					
Crop	Total Irrigation Water Use [m³/acre]	Crop Yield [kg/acre]	Net Income [Rs/acre]	Water Productivity in Main Product [kg/m³]	Water Productivity [Rs./m³]
Paddy	3518.5	1169.5	548.8	0.57	0.32
Maize	598.7	941.7	1629.3	1.53	6.44
Bajra	1497.9	6025.0	3425.5	7.82	0.43
Wheat	915.4	1003.6	754.1	1.97	4.45
Barseem	1184.5	4864.6	9474.0	1.72	12.99

Source: authors' own estimates based on primary data

Table 4: Water Productivity Estimates of Different Crops under Canal Irrigation at Changarwan (Zone 1)

Canal Irrigation					
Crop	Total Irrigation Water Use [m³/acre]	Crop Yield [kg/acre]	Net Income [Rs/acre]	Water Productivity in Main Product [kg/m³]	Water Productivity [Rs./m³]
Paddy	5849.8	1661.2	6183.8	0.41	1.50
Maize	2600.0	880.0	4336.2	0.53	2.00
Bajra	1935.8	8122.2	7358.2	10.41	0.09
Wheat	1109.0	1100.6	2465.4	1.57	3.46
Barseem	2488.5	7216.7	16454.0	3.60	24.01

Source: authors' own estimates based on primary data

Table 5: Water Productivity of Different Crops under Well Irrigation at Skohpur (Zone 3)

Well Irrigation					
Crop	Total Irrigation Water Use [m³/acre]	Crop production [kg/acre]	Net Income [Rs/acre]	Water Productivity in Main Product [kg/m³]	Water Productivity [Rs./m³]
Paddy	4548.0	2270.0	12520.7	0.79	4.46
Maize	1381.0	1060.0	310.3	3.30	6.34
Bajra	1040.9	5607.8	-244.40	17.21	0.37
Wheat	697.5	1494.1	8584.8	3.41	19.80
Barseem	3050.6	6214.3	12676.8	3.52	30.28

Source: authors' own estimates based on primary data

Table 6: Water Productivity Estimates of Different Crops under Canal Irrigation at Village Skohpur (Zone 3)

Canal Irrigation					
Crop	Total Irrigation Water Use [m³/acre]	Crop production [kg/acre]	Net Income [Rs/acre]	Water Productivity in Main Product [kg/m³]	Water Productivity [Rs./m³]
Paddy	11722.6	1766.7	3966.2	0.20	0.06
Maize	2836.1	1260.0	6656.4	9.15	1.99
Bajra	6433.6	4500.0	1752.2	1.45	1.03
Wheat	1787.0	1592.9	9820.0	2.37	14.32
Barseem	2382.3	5400.0	11263.7	2.41	10.56

Table 7: Water Productivity Estimates of Different Crops under Conjunctive use of Irrigation at village Skohpur (Zone 3)

Conjunctive Use					
Crop	Total Irrigation Water Use [m³/acre]	Crop production [kg/acre]	Net Income [Rs/acre]	Water Productivity in Main Product [kg/m³]	Water Productivity [Rs./m³]
Paddy	7740.0	2188.9	11628.3	0.79	4.19
Maize	1247.4	783.3	1635.8	0.73	1.50
Bajra	475.20	8600.0	4400.0	9.05	4.38
Wheat	1745.0	1518.3	9528.8	2.51	16.99
Barseem	3909.6	5675.0	8869.40	3.76	9.73

Source: authors' own estimates based on primary data

5.3. Impact of Quality and Reliability of Irrigation on Water Productivity of Crops

Table 8 shows the estimates of irrigation quality index for five major crops under two major sources of irrigation, viz., wells and canals, and the corresponding estimates of physical and economic productivity of water for these crops for Changarwan village. It can be seen that in situations where the irrigation quality index is higher, the water productivity in economic terms is higher. The only exception is barseem. Another interesting observation is that water productivity in economic terms does not follow the same trend as that of physical productivity of water. The physical productivity of water was found to be higher for fields, which have lower irrigation quality index, in the case of paddy, bajra and barseem.

One reason for this could be the difference in duration of the crop between fields under different sources of irrigation. In crops such as bajra and barseem where only leafy biomass is harvested, if water is available in plenty through excessive water delivery, farmers might take more harvests of these fodder crops with more number of irrigations. This would reduce the value of IQ, but may not reduce physical productivity of water as the biomass output would increase in proportion of the amount of water.

Table 8: Productivity of Water for Crops at Changarwan (Zone 1)

Crop	Source of Irrigation	Irrigation Quality Index	Water Productivity (kg/m^3)	Water Productivity (Rs/m^3)
Paddy	Well	2.66	0.57	0.32
	Canal	3.33	0.41	1.50
Maize	Well	10.28	1.53	6.44
	Canal	0.65	0.53	2.00
Bajra	Well	1.37	7.82	0.43
	Canal	0.25	10.41	0.09
Wheat	Well	2.26	1.97	4.45
	Canal	0.5	1.57	3.46
Barseem	Well	0.44	6.53	12.99
	Canal	0.17	10.23	24.01

Source: authors' own estimates based on primary data

Table 9 shows the estimates of irrigation quality index for five major crops under well irrigation, canal irrigation and conjunctive use, and the corresponding estimates of physical productivity and economic productivity of water for these crops for Skohpur village. Similar to what was seen in the case of Changarwan, comparing well irrigated crops and canal irrigated crops in Skohpur shows that water productivity (Rs/m^3) was found to be higher for fields which have higher estimated values of irrigation quality and reliability except paddy.

Table 9: Productivity of Water for Crops at Skohpur (Zone 3)

Crop	Source of Irrigation	Irrigation Quality Index	Water Productivity (kg/m^3)	Water Productivity (Rs/m^3)
Paddy	Well	26.77	0.79	4.46
	Canal	13.51	0.20	0.06
	Conjunctive	28.16	0.79	4.19
Maize	Well	2.63	3.30	6.34
	Canal	2.2	9.15	1.99
	Conjunctive	5.01	0.73	1.50
Bajra	Well	1.44	17.21	0.37
	Canal	2.29	1.45	1.03
	Conjunctive	1.16	9.05	4.38
Wheat	Well	1.05	3.41	19.80
	Canal	0.87	2.37	14.32
	Conjunctive	1.25	2.51	16.99
Barseem	Well	1.43	3.33	30.28
	Canal	1.17	2.41	10.56
	Conjunctive	0.32	2.02	9.73

Source: authors' own estimates based on primary data

5.4 How Water Productivity in Crop production Changes with Quality and Reliability of Irrigation Water?

We have begun our analysis with the premise that improved quality and reliability of irrigation, expressed in terms of irrigation quality index (IQ), would be able to manipulate the water productivity parameters through controlling the major drivers of change in water productivity such as irrigation dosage, fertilizer and pesticide inputs.

Increase in irrigation dosage, largely, increases the beneficial evapo-transpiration from the crop, and therefore the crop yield. But, excessive irrigation will not have any positive effect on crop yields. On the other hand, it increases the value of denominator of water productivity. We have seen that the IQ values are much higher for well-irrigated fields for both the locations. Simultaneously, the irrigation dosages are much higher in canal irrigated fields as against well-irrigated fields for most crops in Changarwan. Also, it was much higher in canal irrigated fields and field irrigated by both canals and wells, than that of well irrigated fields for most crops in the case of Skohpur. This means that the highest influence of IQ index is in controlling the water delivery in the field.

Excessive dosages of irrigation are likely to reduce both the physical and economic productivity of water. But, fertilizer and pesticide dosage and labour input are also other drivers of change in water productivity as they can increase the yield, without changing the denominator of water productivity in kg/m^3. Generally, their effect on physical productivity of water would be positive. At the same time, these inputs can increase the cost of production significantly, and therefore its marginal impact on the net returns may not always be positive. We have begun our analysis with the assumption that better quality and reliability in irrigation services would lead to optimal use of other inputs such as fertilizers, pesticides and labour.

Comparative analysis of crop inputs such as fertilizer, pesticide and labour use between crops, which receive irrigation of differential quality and reliability does not fully support this hypothesis. In Changarwan, for instance, the change in levels of fertilizer and pesticide dosage with change in source of irrigation was found to be significant only for paddy, wheat and maize. What emerges from the comparison is that the dosage of these inputs does not increase with increase in reliability of irrigation water (Table 12). This is evident from the fact that canal-irrigated fields, which have lower reliability, do not necessarily receive lower dosage of fertilizer and other inputs. One reason could be that as the irrigation dosage is very high in the case of canals resulting in heavy percolation, farmers provide for leaching of fertilizers, which occur due to it. Another reason could be that the quality and reliability does not matter so much for fodder crops such as bajra and barseem, farmers try to obtain higher yield through higher dosage of inputs. Significant difference in labour use was found between sources, for three crops viz., paddy, maize, and barseem. Here, contrary to what was generally perceived, labour input was higher for fields, which received irrigation water of lower reliability.

Analysis for Skohpur (Table 13) shows that there is no general pattern in the input use vis-à-vis source of irrigation or quality and reliability of irrigation. Similarly in the case of labour input also, no general pattern is seen to be emerging. As a result, lower quality and reliability of irrigation does not necessarily result in lower water productivity in physical terms, but in economic terms, as shown by majority of the cases from both the field locations.

Table 12: Comparison of Input Use and Water Productivity in Economic Terms at village Changarwan (Zone 1)

Crop	Source of Irrigation	Irrigation Quality Index	Input Use (Rs./acre)		Labour (Rs./acre)	Water Productivity (Rs./m^3)
			Fertilizer	Pesticide		
Paddy	Well	2.66	607.8	179.0	1393.81	0.32
	Canal	3.33	701.5	157.0	1207.37	1.50
Maize	Well	10.28	566.3	135.5	333.3	6.44
	Canal	0.65	272.3	196.2	666.6	2.00
Bajra	Well	1.37	215.0	-	1200	0.43
	Canal	0.25	242.9	-	-	0.09
Wheat	Well	2.26	629.1	176.0	918.6	4.45
	Canal	0.5	775.5	169.8	944.6	3.46
Barseem	Well	0.44	438.5	120.0	560	12.99
	Canal	0.17	426.5	350.0	300	24.01

Source: authors' own estimates based on primary data

Table 13: Comparison of Input use and Water Productivity in Economic Terms at village Skohpur (Zone 3)

Crop	Irrigation Quality Index	Source of Irrigation	Fertilizer (Rs./acre)	Pesticide (Rs./acre)	Labour (Rs./acre)	Water Productivity (Rs./m^3)
Paddy	26.77	Well	1004.9	151.9	1032.0	4.46
	13.51	Canal	857.70	245.7	1195.2	0.06
	28.16	Conjunctive	1019.4	196.0	1047.6	4.19
Maize	2.63	Well	954.0	228.4	1201.2	6.34
	2.2	Canal	1058.7	148.9	966.6	1.99
	5.01	Conjunctive	1007.3	178.3	281.5	1.50
Bajra	1.44	Well	345.0	-	845.0	0.37
	2.29	Canal	500.0	55.0	500.0	1.03
	1.16	Conjunctive	-	-	-	4.38
Wheat	1.05	Well	835.2	199.2	824.8	19.80
	0.87	Canal	1080.7	206.7	727.7	14.32
	1.25	Conjunctive	875.9	165.6	1300.0	16.99
Barseem	1.43	Well	535.9	-	-	30.28
	1.17	Canal	591.0	495.0	466.6	10.56
	0.32	Conjunctive	675.0	175.0	-	9.73

Source: authors' own estimates based on primary data

The quality and reliability of irrigation had some impact on the cropping pattern chosen by the farmers. The well irrigators in Changarwan were allocating more area under maize during kharif season as compared to canal irrigators (see Table 14 and 15). Obviously, maize is a low water consuming crop when compared to paddy. But, it is not a highly water-efficient crop either. There are two reasons for greater preference for maize. One is the water shortage during summer months induced by restricted power supply in the farms. The other is the high cost of diesel required for pumping groundwater. In Punjab, monsoon arrives in the first week of July, while the transplanting of paddy starts in June itself. During the month of June, the potential evapo-transpiration of the crop rapidly goes up due to very high temperatures and high aridity, and the crop needs frequent waterings. This makes paddy production with diesel pump irrigation an un-attractive proposition for the farmers. But, the canal irrigators in the same village get plenty of canal water for paddy, with good reliability as seen from the estimates of quality and reliability of canal water supply for paddy in that village. Hence, they are able to allocate more land for paddy.

Contrary to this, in Skohpur village, the reliability of canal water supply is very poor. This is evident from the discussions with the farmers, and the irrigation quality and reliability index estimated for canal water supplies for paddy. The lower reliability of canal water supplies is forcing farmers to allocate much less area for water-intensive paddy. The main reason for this is that the returns from paddy are dependent on the adequacy of irrigation water applied, as seen from the comparison of net returns from paddy. While the well irrigators get net returns of Rs. 12000 from an acre of paddy, the canal irrigators get Rs.3900 per acre in that village. Hence, we could infer that quality and reliability of water influences the cropping pattern wherein the farmers choose crops, which give higher return from every unit of land they cultivate.

Table 14: Comparison of cropping pattern at village Changarwan (Zone 1)

Crop	% of area under different water source	
	Well	Canal
Paddy	31.41	43.41
Maize	11.42	2.37
Bajra(GF)	5.21	7.14
Wheat	44.85	42.15
Barseem	5.93	4.90

Source: authors' own estimates based on primary data

Table 15: Comparison of cropping pattern at village Skohpur (Zone 3)

Crop	% of area under different water source		
	Well	Canal	Well + Canal
Paddy	24.1	9.99	48.90
Maize	18.5	25.8	7.52
Bajra (GF)	4.56	8.43	1.25
Wheat	42.3	44.5	28.5
Barseem	6.72	10.2	4.7

Source: authors' own estimates based on primary data

6. FINDINGS AND CONCLUSIONS

In this paper, we have developed quantitative criteria for assessing the quality and reliability of irrigation water, and using these criteria, a composite index called the irrigation quality index was developed. The index uses the water control index, a function of water delivery rate; the frequency of irrigations; the duration of irrigation; and the maximum time gap between two consecutive waterings as the determinants. The index was worked for different crops under three different sources of irrigation in Bist Doab area.

Overall, the irrigation quality index was found to be higher for well irrigated fields as compared to canal irrigated fields and fields irrigated by both wells and canals in Skohpur village. But, the estimates of irrigation quality index were found to be higher for canal irrigated fields than well-irrigated fields in the case of Changarwan village for a few crops. This is in confirmation with what the farmers in these villages perceive about the quality and reliability of irrigation water deliveries from canals from the respective villages. Hence, we could conclude that the quantitative criteria evolved for estimation of this composite index are realistic.

Comparison of irrigation quality index estimated for major crops under different sources of irrigation vis-à-vis the water productivity of the respective crops show that differential reliability has an impact on economic productivity of water (Rs/m^3). The fields, which received irrigation water of higher quality and reliability got higher water productivity in rupee terms. But, the impact of differential quality and reliability was not visible on physical productivity of water for fodder crops.

Contrary to the belief that higher quality and reliability of irrigation would result in better yields, the fields, which were receiving high quality irrigation gave lesser yields as compared to those which received poor quality irrigation. This was primarily due to the high nutrient load which canal water contained that increased the yield of those crops substantially. Also, fodder crops also gave higher yields under less reliable irrigation water supply. Hence, one can conclude that improved quality and reliability of irrigation would help enhance the water productivity in crop production. Nevertheless, the index developed here is not adequate to assess the IQ of crops, which can be harvested many times. Also, it needs refinement to take into account the difference in chemical quality of irrigation water.

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