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Case Study

Spatio-temporal Assessment of Productivity in Pehur Main Canal System, Pakistan

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Abstract: This study aimed at assessment of productivity in Pehur Main Canal system on Spatio-temporal basis. The water appropriation is based on warabandi scheduling system. The data for this study was collected from official record of irrigation department and field survey. Productivity is assessed on a scale of zero to one (0-1), one represents maximum productivity and zero indicates nil productivity. The analysis revealed most of productivity values closer to zero. Temporally productivity is better in Rabi season than Kharif Miana (dry summer season). On spatial scale, the productivity in both Rabi and Kharif Miana seasons is random in most of secondary canals. In majority of canals, the productivity is better in the middle and tail sections then the respective heads and tails. This situation shows lack of operational maintenance of the irrigation scheme. Findings of this study can be used to rectify the operational management of the irrigation system to enhance productivity.

Keywords: Pehur Main Canal system, Spatio-temporal Productivity, Irrigated agriculture, Area Productivity, Kharif Miana.

1. INTRODUCTION

Irrigated agriculture provides 45% of the world's total food supplies, and without it, it will not be possible to feed our planet's population [1, 2, 3, 4, 5, 6]. Irrigation is the main source of increased food production worldwide and especially in Asia [7, 8, 9, 10, 11, 12]. Irrigated agriculture plays a fundamental role in the economic development and social uplift of the non industrialized nations in the world [13, 14]. According to estimate the world population will increase from the base of 6.1 billion in year 2001 to 9.3 billion by 2050. In the mean time, the population of 49 least developed countries will increase by three folds in size [15, 16, 17, 18]. This population growth will pressurize irrigated agriculture to considerably increase food production in the future [19, 20, 21,].The estimated 60% of additional food requirements through 2050 will have to be met by production on irrigated land [22, 23]. Therefore the future food security of our planet entirely depends upon irrigated agriculture [24, 25, 26, 27].

The productivity of irrigated agriculture is related to output in response to inputs added to the system [28, 29, 30, 31, 32, 33]. A number of indicators are used for the measurement of productivity. The irrigated agriculture has a number of outputs which are area irrigated, crop produce, the economic value of the crop produced [34, 35, 36, 37, 38, 39]. The productivity indicators are easy to asses both temporally and spatially [40, 41, 42, 43]. The productivity can be calculated in response to certain inputs or in gross terms by measuring outputs. The important inputs in the irrigated agriculture are water, land and financial resources [44, 45, 46, 47, 48]. The productivity is more relevant when it is measured in response to inputs which are scares. The researchers [49, 50, 51, 52, 53, 54] have listed a number of indicators for the measurement of productivity. These indicators can be summarized as total area irrigated, total crop production and total economic benefits in gross terms, and total irrigated area, total production and total economic benefits per unit of water applied,

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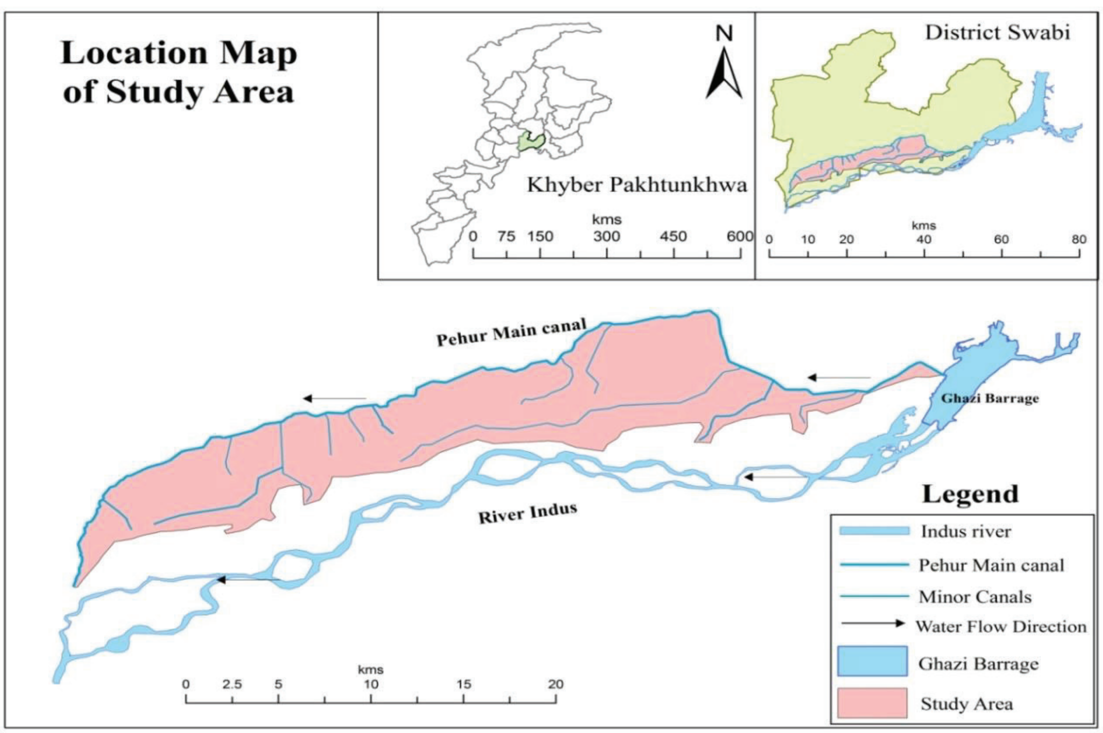
cropped area or total area available in net terms. The water applied for irrigation at multiple levels is measured in the irrigation system, i.e. from the head of a canal up to field level of the cropped area [55, 56, 57, 58, 59]. In all performance assessment studies of irrigation schemes, productivity indicators are included which are easy to quantify [60, 61, 62, 63].

Productivity is the ultimate goal of each and every economic activity. Agriculture is one of the basic economic activities and irrigation in arid and semi-arid regions significantly enhances food production [64, 65, 66]. Arid and semi-arid regions have a scarcity of fresh water resources therefore, it is necessary to use these limited resources as efficient as possible to increase their utility [67, 68]. Although irrigated agriculture is the most promising means of increased food production but inefficient use of water can cause damage to soil in addition to wastage of this precious resource. It is therefore necessary to assess the Spatio-temporal productivity of irrigated agriculture to point out areas where improvement can be made to enhance food production.

The Pehur Main Canal (PMC) system in District Swabi of Khyber Pakhtunkhwa was selected for the assessment of productivity. The study area is located along the southern boundary of district Swabi [Fig 1]. The area runs parallel to River Indus along its right bank. The canal takes its water supply from the Ghazi barrage and distributes it over the command area through main canal and twelve (12) distributaries and minors [69, 70]. There are three distinct cropping seasons in the study area. These are winter (Rabi), dry summer (Kharif Miana) and rainy (Kharif). In Rabi season little rainfall is received and loss of water through evapotranspiration is least so the demand for irrigation remains low. The rainfall is low in the dry summer season while the consumptive loss of water is high due to evapotranspiration so cropping is restricted and requiring frequent irrigation [68, 71]. During Kharif season maximum rainfall is received from monsoon. Due to abundant rainfall, the crops does not need frequent irrigation and only one or two protective irrigations are sometime required. The dams are filled to their capacity and the rivers are often flooded so the rainy (Kharif) season is not included in this study [36, 68, 72].Consequently, the Rabi and dry summer crops were considered



Source: Map in Arc GIS from Toposheets and Google earth map

Fig. 1. Location of the study area, District Swabi, KP, Pakistan

for the assessment of productivity spatially in head, middle and tail sections of the main and secondary canals and temporally during Rabi and dry summer Seasons.

2. MATERIALS AND METHODS

2.1 Measurement of Productivity

The water allocation plan followed in the study area is based on warabandi scheduling system. The water is provided for fixed time duration proportional to the size of the land holding [68, 73]. The main objective of warabandi system is to distribute available water resources equally over as large area as possible. The total area irrigated is the variable of interest in the measurement of productivity. The measurement of productivity must be in relation to certain standard which in this case is the targeted area to be irrigated. The productivity is dependent on the water distribution amongst various allocation units along the distribution channels (main, secondary and tertiary canals) [34, 35, 36, 37, 53, 60]. The proposed measurement of productivity is to use the indicators in comparison to certain standards. The standards can be target values, or the values associated with land or water, or the values associated to maximum output management strategy in response to certain inputs [39, 40, 41, 44, 62]. The proposed indicators for the measurement of area productivity are given in the following equation.

$$\mathrm{Prg} = \frac{\mathrm{OAa}}{\mathrm{OAt}}$$

Where the Prg = Area productivity, OAa = actual output (total area irrigated during an irrigation season i.e. Rabi or Kharif Miana, OAt = targeted output (total area planned to be irrigated during an irrigation season). Productivity in different sections of the canal can be measured by considering allocation units in these sections.

2.2 Data Collection

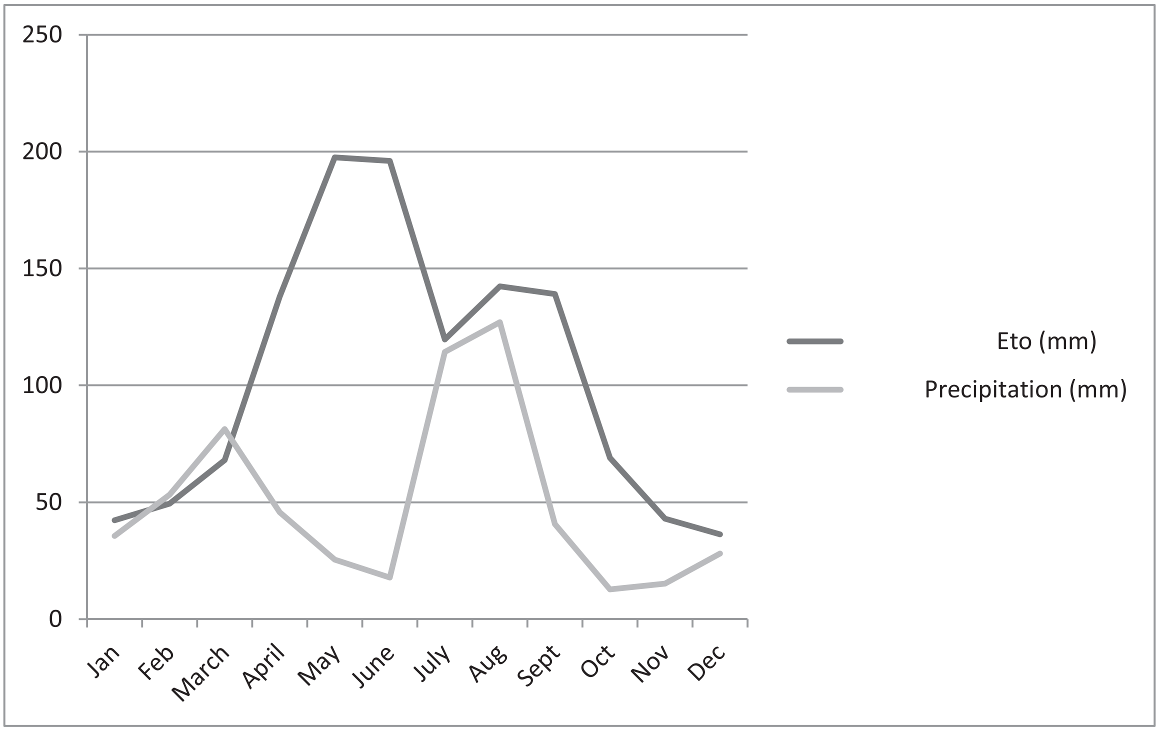
The data for this study was collected both from primary and secondary sources. The sub-divisional offices of Provincial Irrigation Department (PID) keep records of the irrigation activities. Among the records kept are Outlet Registers (*Mogawar*) maintained by the irrigation staff. The 'Outlet Registers' refer to designed discharge, area to be irrigated, area actually irrigated, crops assessed in each growing season, water tax (*abiyana*) collected in each growing season. The allocated discharge flow of each outlet was obtained from the allocation plans. For delivered volume of water an extensive survey was conducted from 1st October 2013 to 15th January and from 1st to 31st March 2014 for Rabi season while from 1st April to 30th June 2014 for Kharif Miana season. The canal system remains closed for desiltation and necessary repairs from 16th January to 28th February each year. The total 250 outlets were divided into ten groups of 25outlets in each. Only one group of outlets was surveyed on daily basis so that each group had its turn on every tenth day. The flow data was recorded and compiled for each individual outlet for both seasons. The data was analyzed for assessment of reliability in both seasons and in different sections of main and secondary canals [68, 74].

3. RESULTS AND DISCUSSIONS

Irrigated agriculture is an economic activity employing bulk of labour force especially in the developing countries. The strategy of each farmer is to increase the crop produce with minimum possible input resources. The resources of interest in an irrigation scheme are land and water. With limited water resources in the study area, the farmers are always in pursuit of increasing productivity. The productivity is measured on a scale of 0-1(zero to one), where 1 (one) represents highest productivity and 0 (zero) indicates nil productivity. In the PMC irrigation system the overall productivity remains low. The Rabi season registers a slightly higher productivity than the dry summer season. The Spatio-temporal analysis of productivity is discussed in following pages.

3.1 Productivity of Pehur Main Canal system during Rabi season

The Rabi season extends from October of one year to March of next year. Both evapotranspiration and rainfall are low during Rabi season [Fig. 2]. The irrigation demand remains low owing to a small gap between precipitation and potential loss of water through evapotranspiration. Due to low irrigation demand irrigation interval is increased from 07 days to 14 days. Locally this setup is called week



Source: Sugarcane Research Institute, Mardan.

Fig. 2. Crop-Water requirements in the Study Area

Table 1. Productivity Comparison of Pehur Main Canal system (Spatio-temporal)

	Name of canal	Rabi			Kharif Miana		
		Head	Middle	Tail	Head	Middle	Tail
H	PMC (head-section)	0.435	0.152	0.489	0.261	0.057	0.241
E	Topi Minor	0.353	0.359	0.149	0.192	0.248	0.098
A	Zarobi Minor	0.471	0.570	0.412	0.255	0.258	0.168
D	Kotha Distributary	0.465	0.367	0.628	0.289	0.214	0.240
-	Kaddi Minor	0.740	0.440	0.513	0.348	0.242	0.238
M	PMC (Mid-section)	0.473	0.384	0.510	0.225	0.323	0.370
I	Zaida Minor	0.553	0.549	0.421	0.214	0.227	0.221
D	Sheikh Dhari Minor	0.487	0.854	0.679	0.431	0.722	0.358
D	Zakarya Minor	0.400	0.319	0.282	0.412	0.206	0.165
LE	Lahore Minor	0.578	0.349	0.326	0.463	0.245	0.198
T	PMC (Tail-section)	0.617	0.561	0.322	0.209	0.181	0.131
A	Thanodher Distributary	0.513	0.347	0.074	0.203	0.123	0.036
I	Bazar Minor	0.361	0.134	0.048	0.122	0.024	0.009
L	Manki Minor	0.558	0.525	0.205	0.149	0.160	0.126
-	Jahangira Minor	0.325	0.440	0.247	0.125	0.126	0.054
	Average	0.488	0.419	0.353	0.260	0.223	0.177

Source: GoKP (2012), Field Survey, 2013-14.

wise schedule (*haftawari*), this means that each secondary canal get water on alternate weeks. The farmers on secondary canals can irrigate their crops on every 14th day. The low demand for irrigation helps to irrigate more area therefore productivity comparatively remains high as compared to dry summer season (Kharif Miana). The overall average productivity of Pehur Main Canal system in Rabi season is, head (0.488), middle (0.419) and tail (0.353) [Table 1]. The productivity in different sections of the PMC system with respective canals is discussed below.

3.1.1. Productivity in Head Section of Pehur Main Canal system (Rabi)

The head of the PMC system comprises head of main canal, Topi minor, Zarobi minor, Kotha distributary and Kaddi minor canals. The head section of main canal is again stratified into head, middle and tail sections. The highest productivity during Rabi season is recorded in the head of Kaddi minor (0.74) located in the lower head instead of upper head section of the PMC system. Kaddi minor also has better productivity in the tail than the middle section. On the contrary the lowest productivity (0.149) is observed in the tail of Topi minor located at head of canal system. Kotha distributary records higher productivity at the tail and Zarobi minor has higher productivity in middle than its head [Table 1]. The inter-canal comparison shows no proper sequence of change from upper head to lower head of the system in all sections of the minor canals. Higher values of productivity are observed in the lower head of the system instead of upper head. The higher productivity of Kotha distributary in the tail section is attributed to Badri Lift Irrigation Scheme which supplements the water supply in the tail section of the distributary.

3.1.2. Productivity in Middle Section of Pehur Main Canal system (Rabi)

In the middle section of the PMC system the canals included are mid-section of main canal, Zaida minor, Sheikh Dhari minor, Zakarya minor and Lahore minor. The main canal has better productivity in lower mid-section than the upper sections (0.473, 0.384 and 0.510). The Sheikh Dhari minor canal has the highest productivity of the system in its middle (0.854) while its tail (0.679) performs better than its head (0.487). The Zaida, Zakarya and Lahore minor canals have higher productivity at the head steadily decreasing towards the tail [Table 1]. The comparison among canals of this part of irrigation system show irregular changes in productivity values from upper to lower mid-section. The head, middle and tail of all constituent canals show variations with no ascending or descending order. The random distribution of productivity values indicates that either the farmers interfere in the operation of main canal to divert more water into the secondary canals or the system is not maintained at recommended level of flow which results in irregular distribution of water among the secondary canals.

3.1.3. Productivity in the Tail Section of PMC system (Rabi)

The canals included in the tail section of the PMC system are tail end of main canal, Thanodher distributary, Bazar minor, Manki minor and Jahangira minor. The tail of main canal included is again divided into head, middle and tail section for analysis. The section of main canal has better productivity than the head and middle sections of the main canal (0.617, 0.561 and 0.322). All the minor canals in this part of the system show a normal behavior having higher productivity at the head decreasing towards the tail with exception of Jahangira minor canal which has better productivity in the middle than the head. The lowest productivity of entire system during Rabi season is in the tails of Thanodher distributary (0.074) and Bazar minor (0.048) [Table 1]. The inter-canal comparison demonstrates a normal behavior in the head sections of the main and minor canals with exception of Manki minor. All the minor canals retain a better productivity in the head sections than the middle and tail sections. The middle sections show steady decrease up to Bazar minor then an increase afterwards. The same pattern of productivity is prevalent in tail sections of main and minor canals.

3.2 Productivity of PMC system during dry summer season (Kharif Miana)

The Kharif Miana (dry summer season) is characterized by very hot and dry weather. The rainfall is normally very low and erratic. The evapotranspiration rate is highest during this season and a very wide gap between the monthly received precipitation and evapotranspiration exists [5, 11]. Therefore irrigation demand remains high during this season [Figure 2]. The irrigation interval in dry summer season is 07 days. The crops grown during this season are Tobacco (Virginia and local), Watermelons, Muskmelons, and Maize and fodder crops. All these crops need intensive irrigation throughout the growing season. Virginia tobacco is so much water dependent that from mid May onwards it has to be irrigated on every alternate 4^{th} day. To manage this situation the framers normally leave half or two-third of their land fallow this season. The farmers frequently exchange warabandi turns to cope with this extraordinary situation. The water availability in the reservoir is satisfactory during this season but owing to very high evapotranspiration rate and the high demand of crops like Tobacco and Watermelons the cropping remain limited. Apart from irrigation a lot of people are dependent on canal water for their domestic water needs which increases many folds during this season. These conditions essentially limit the productivity during the Kharif Miana season. The productivity as a whole remains low during this season owing to high demand of crops for irrigation and limited availability of irrigation water. The average productivity values for the system are (0.260), (0.223) and (0.177) in the head, middle and tail respectively [Table 1]. The productivity in various sections of Pehur Main Canal system during Kharif Miana season is analyzed below.

3.2.1 Productivity in Head-Section of Pehur Main Canal system (Kharif Miana)

The lowest values of productivity in the head of the system are observed in the middle section of main canal (0.057) and tail of Topi minor canal (0.098). The highest productivity of this section is in the head of Kaddi minor located in the lower head of the system rather than the upper head. Kaddi minor canal has more productivity in the head decreasing towards the tail (0.348, 0.242 and 0.238). All other canals in head section of the system do not show normal behavior. Main canal has more productivity in the lower than middle head; Topi and Zarobi minor canals have more productivity in middle than head and Kotha distributary has high productivity in the tail than middle section. The inter-canal comparison show a decreasing trend of productivity from the upper to lower head of the system in the head sections of constituent canals while their respective middle and tail sections demonstrate a mixed trend [Table 1].

3.2.2 Productivity in middle Section of Pehur Main Canal system (Kharif Miana)

The productivity is better in middle and lower parts of this section of the irrigation system during Kharif Miana season. Individually highest productivity (0.722) is in the middle section of Sheikh Dhari minor which is also higher than the head section of the same minor canal. The part of main canal in this section has better productivity in the tail than respective middle and head sections (0.225, 0.323 and 0.370). The Zaida minor canal has better productivity in middle and tail than the head section. The Zakarya and Lahore minor canals have descending sequence of productivity from head to tail sections. Comparatively productivity is high in this section with respect to head and tail of the system but the inter-canal comparison does not show any logical progression of change from upper to lower mid-section. The head of Zaida minor canal located upstream has a lower productivity (0.214) while head of Lahore minor canal, located downstream has higher productivity (0.463) [Table 1].

3.2.3 Productivity in Tail-Section of Pehur Main Canal system (Kharif Miana)

The tail section of Pehur Main Canal system is least productive in Kharif Miana season. The highest productivity in this section of the system is (0.209) in the upper tail of main canal and the lowest is (0.009) in the tail of Bazar minor. The tail ends of Thanodher distributary, Jahangira minor while both middle and tail sections of Bazar minor have a very low productivity. The main canal, Thanodher distributary and Bazar minor canals show a usual trend of more productivity in the head decreasing towards tail. The inter-canal comparison show a decreasing trend in the heads of constituent canals while in middle and tail sections of these canals the sequence is broken by very low productivity in tail of Thanodher distributary and in both middle and tail of Bazar minor canal. The productivity in this section from upper to lower tail of the system ranges from 0.209 to 0.009 [Table 1]. The comparatively better productivity in Manki minor canal is due to its short span and less number of water users. Otherwise sever water shortages are felt in the tail sections of all minor canals in this part of the system.

4. CONCLUSION

Productivity is one of the major objectives of all irrigation projects. The productivity of Pehur Main Canal system is assessed on location and seasonal basis. It is measured on a scale of zero to one (0-

1). In ideal conditions the productivity values will be closer to one (1) and the average of all values from head to tail must also be closer to 1. Data analysis shows majority of values closer to 0 (zero). This situation indicates low level of performance of Pehur Main Canal system. On system level average productivity values in head, middle and tail sections are, Rabi (0.488, 0.419 and 0.353) and Kharif Miana (0.260, 0.223 and 0.177) [Table 1]. The average productivity show a normal trend of higher values at head decreasing towards tail in both seasons. Overall few productivity values are higher than half of scale, for instance four (4) in head, six (6) in middle and five (5) in tail of the irrigation system. These higher values are more frequent in middle and tail sections than head. Another aspect coupled with low level of productivity is its irrational distribution among different sections of the main, distributaries' and minor canals.

The data analysis reveals that on individual canals level some middle sections doing better than heads while tails better than middle and head sections. This illogical behavior indicates lack of operational maintenance of the Pehur Main Canal system. The canal systems which operate under the warabandi system have water receiving structures which are sensitive to the flow of water in the main, distributaries and minor canals. Canals flowing up to 70% of their design capacity or above the water drawing structures will behave normally. The water flow below 70% of the full capacity of the canal induces abnormal changes in drawing water by the outlets. The distribution of productivity indicates a lack of management on part of the irrigation staff and lack of organization among the farmers. These irregular changes indicate that system is not maintained properly which induces the water withdrawing structures to behave abnormally. This results in irrational distribution of water and hence the performance of the system becomes erratic.

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