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Use of GIS for the Performance Evaluation of Canal Irrigation System in Rice Wheat Cropping Zone

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Abstract**—**The research study evaluated the performance of irrigation system by using special scientific tools like Remote Sensing and GIS technology, so that proper measurements could be taken for the sustainable agriculture and water management. Different performance evaluation parameters had been calculated for the purposed data was gathered from field investigation and different government and private organizations. According to the calculations, organic matter ranges from 0.19% (low value) to 0.76% (high value). In flat irrigation system for wheat yield ranges from 3347.16 to 5260.39 kg/ha, while the total water applied to wheat crop ranges from 252.94 to 279.19 mm and WUE ranges from 13.07 to 18.37 kg/ha/mm. For rice yield ranges from 3347.47 to 5433.07 kg/ha with total water supplied to rice crop ranges from 764.71 to 978.15 mm and WUE ranges from 3.49 to 5.71 kg/ha/mm. Similarly, in raised bed system wheat yield ranges from 4569.13 to 6008.60 kg/ha, total water supplied ranges from 158.87 to 185.09 mm and WUE ranges from 27.20 to 33.54 kg/ha/mm while in rice crop, yield ranges from 5285.04 to 6716.69 kg/ha, total water supplied ranges from 600.72 to 755.06 mm and WUE ranges from 6.41 to 10.05 kg/ha/mm. Almost 51.3% water saving is observed in bed irrigation system as compared to flat system. Less water supplied to beds is more affective as its WUE value is higher than flat system where more water is supplied in both the seasons. Similarly, RWS values show that maximum water deficit while minimum area is getting adequate water supply. Greater yield is recorded in bed system as plant per square meter is more in bed system in comparison of flat system Thus, the integration of GIS tools to regularly compute performance indices could provide irrigation managers with the means for managing efficiently the irrigation system.

Keywords**—**Field survey, Relative Water Supply (RWS), Remote sensing maps, Water Use Efficiency (WUE).

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I. INTRODUCTION

DEVELOPMENT in agriculture plays a fundamental role in the sustainability of economy of countries like Pakistan. Rice and wheat are among the major cash crops of Pakistan that has account 1.3% and 2.8% in GDP, respectively, in the year 2008-09 (GOP, 2008-09) [16].

The rice-wheat cropping system has been practiced by farmers in Asia for more than 1000 years. It covers 13.5 million ha (Mha) in South Asia: India (10.0 Mha), Pakistan (2.2 Mha), Bangladesh (0.8 Mha) and Nepal (0.5 Mha). It represents 32% of the total rice area and 42% of the total wheat area in these countries (Ahmad and Iram, 2004) [2]. Wheat being a major principle food of about 180 million people and annually grown on approximately 8.61 million hectares with annual production of 25 million tons while per hectare average production is 2,585 kg (Anonymous, 2008-09) [7].

Irrigation plays a key role in the development of agriculture sector of any country. Pakistan is severely affected by water scarcity and is already one of the most water-stressed countries in the world. The irrigation system of Pakistan was designed for the cropping intensity of about 70% and this figure has increased up to 200% due to the food requirement of the growing population. By the year 2008 and 2009 the area irrigated by canals and tubewells for agricultural practices was 19.27 Mha [16]. The demand for water is likely to grow from 4 to 15% of aggregate water demand in the next twenty years [16]. These drastic changes have put a question mark on the agriculture growth and subsequently agriculture scientists have to turn to advanced techniques such as Remote Sensing (RS) and Geographic Information System (GIS) techniques for crop assessment and evaluation of existing irrigated lands.

Performance assessment is regarded as the most pivotal element for improving irrigation management. The science of evaluating irrigation systems has undergone major development during the last 30 years, moving from a focus on classical irrigation efficiencies (Bos and Nugteren, 1974; Jensen, 1977) [11], [18] to performance indicators (Bos et al., 1994; Clemmens and Bos, 1990) [9], [13] and more recently, to frameworks of water accounting and productivity (Molden, 1997; Burt et al., 1997; Clemmens and Burt, 1997) [20], [12], [14]. Irrigation performance indicators range from water distribution to agricultural, economic, social, and environmental aspects [9]. Performance is assessed for a variety of reasons i.e. to improve system operations, to appraise progress against strategic goals, as an integral part of performance-oriented management, to assess the general health of a system, to evaluate impacts of interventions, to diagnose constraints, to better understand determinants of performance, and to compare the performance of a system with others or with the same system over time.

There are a number of well known and emerging irrigation management objectives and needs in Pakistan. In the Punjab, large quantities of irrigation flow are derived from unaccounted groundwater, and there are fears of long term over abstraction and also of degradation due to salt mobilization from existing saline areas. The surface system is supplied by snow-melt from the Himalaya, and varies with snowfall and glacier melt behavior, which is now thought to be being severely modified by global warming. In addition to supply side challenges, water distribution in Pakistan is complex and easily subject to manipulation. Although groundwater use is widespread, surface water is highly valued for its good quality, but equity in distribution is known to be poor, with tail-enders suffering irregular and limited deliveries. Surface and groundwater interactions and their quantification at basin scale are not well understood, but underpin the long term sustainability of irrigated agriculture in the region (Ahmad et al., 2005) [3]. GIS and geo-statistics approaches, along with limited field data, were used for this study because the implementation of modern technologies like GIS for the performance evaluation of irrigation systems has been slow in most developing countries and especially in rice-wheat systems despite the advantages of these technologies.

In 2006, the Government of Punjab launched a new program to maintain a computerized database for irrigation releases to improve irrigation management, reduce rent seeking, increase transparency and demonstrate which users are getting what quantity of water (http://irrigation.punjab.-gov.pk). It is expected that these initiatives will improve data management and availability of surface supplies. But to work, information on overall water consumption (surface and groundwater) at various scales will be essential for judicious and efficient water resources management in Pakistan. There is a need to study water distribution and consumption patterns and the impacts of this on productivity. Better estimates of crop area and actual water consumption are required, since surface water supplies are not only used directly in the field, but also provide a substantial, but unquantified portion of groundwater recharge (Ahmad et al., 2009) [4]. Therefore, there is a pressing need to evaluate the performance of irrigation system by assessing different improvement options on the irrigation system in the rice-wheat zone and to evaluate the performance of irrigation system, using GIS technology.

II. Materials and Methods

A. Description of Study Area

The research was accomplished in the rice-wheat area of Faisalabad, at khurrianwala distributary. The area lies between 30o 45' to 31o 45' N and 72o 43' to 73o 32' E. The soil type in khurrianwala distributary command area is loam to clay loam, which is good for growing all types of crops, vegetables and fodder. The soil ph ranges from 7.5 to 8.2. The soil is good in organic matter. In some part of the area salinity problem is observed. The climate of the region is semi-arid subtropical continental. Mean annual rainfall ranges from 200 to 430 mm, two third of which is received in the form of high intensity shower during monsoon. Irrigation is sufficient for 70% to 75% cropping intensity. About 70% of outlets at Khurrianwala have been lined through last few decades as per policy of water management but the problem lies with the earthen section of the watercourse which is not properly leveled and poorly aligned. Conveyance losses are very pertinent due to irregular section and uneven bed of watercourse.

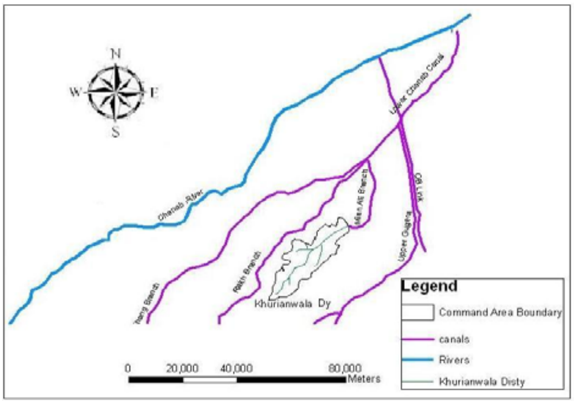

Fig. 1 Command area of Khurrianawala distributary

B. Survey

A field survey was conducted to suggest the management practices in the area like, laser land leveling, deep ploughing for the improvement of crop yeild. Engineering surveys (topographic survey and profile survey) were carried out by the Water Management Research Centre (WMRC) team for leveling and water course improvement. A detailed survey of Chak No. 53-RB was also conducted to locate the Latitudinal and longitudinal position of the experimental fields and watercourse through GPS.

C. Laser Land Leveling

Prior to sowing of each crop season, in order to distribute irrigation water and nutrients evenly throughout the field, precision land leveling was carried out by laser land leveling technique. In crop season of 2008-2009 (Rabi and Kharif) about 29.34 hactares were leveled at Khurrianwala site.

D. Deep Ploughing

Deep ploughing has been done to break the hard pan at deeper parts of the land. This has also helped to remove the problem of interrupted leaching of salts in addition to better root growth.

E. Watercourse Improvement

All the water courses were demolished and then by using tractor driven front blade were rebuilt. Nakkas at all required places have been provided. At Chak No. 49-RB, from main channel to field channels, partial lining was done to enhance smooth water turning as a new approach rather than full lining of the watercourse.

The cut throat flume of size 8" x 3' (throat width x length) was used as it can measure discharge up to 0.0778 m3/s. Measured discharge at middle and tail position in the watercourse was 22.531 m3/s and 14.2116 m3/s, respectively. Overall conveyance efficiency at the downstream of watercourse at Khurrianwala site was 67%.

F. Soil Analysis for Season (2008-09)

Soil samples were collected prior the sowing of each crop for texture analysis, nutrient status and salt status. Soil analyses of samples taken before crop planting help guiding the farmers for fertilizer selection, fertilizer dose, irrigation depths and frequency. At each field undisturbed soil samples were collected with the help of steel auger at two different depths (i.e. 0-6 cm & 6-12 cm).

G. Wheat and Rice Planting

Wheat and rice bed planting was done on 29.34 hactares and 7.689 ha flat planting (control plots for comparison) were completed at Chak No. 53-RB during Rabi and Kharif season. In most of rice bed plantings four rows planted on each bed of 60cm and in some cases one additional line was added in furrow making five rows of rice in bed-furrow system. As far as sowing period is concerned, wheat sowing for Rabi 2008-09 was completed by the month of December and transplanting of rice was completed in the month of June 2009 on different dates.

H. Mapping the Study Area through GPS

A detail survey of the study area was conducted to mark the longitudinal and latitudinal position of the fields and the corresponding water course through GPS in degree decimal system. The water course was marked at three different points i.e. head, middle and tail.

I. Metrological Data

Monthly average temperatures, along with values of monthly averages of daytime wind speed, sunshine hours and minimum relative humidity were collected from metrological department of University of Agriculture, Faisalabad. Weather data were used to compute reference crop evapotranspiration using the FAO-24 modified Blaney–Criddle method (Allen and Pruitt, 1986) [6]. Watercourse level canal discharge values were also collected (Desai et al., 1994) [15].

J. Performance Indices

The irrigation system was evaluated using three performance indices under different categories. The top two indices (adequacy and equity) describe the water delivery system, while the last index, agricultural productivity, describes the irrigated agriculture system.

The adequacy indicator shows to what extent is the quantity of water provided sufficient for the crop growth needs (Abernethy, 1989). The relative water supply (RWS) describes the adequacy of water supply (Levin, 1982) [19]. Equation (1) shows the mathematical equation for calculating RWS.

$$RWS = \frac{IR + RN}{IRG} \tag{1}$$

where, IR is the irrigation water supply, RN the rainfall and IRG the gross irrigation requirement. The major rainfall season, for this region, is June–October, with little rainfall in November–February (rabi season).

The gross irrigation requirement was computed as the net irrigation requirement (IRN) divided by irrigation efficiency. Net irrigation requirement (IRN) was computed using Equation (2).

$$IRN = ETc - Pe \tag{2}$$

where, ETc is the crop evapotranspiration, Pe the effective rainfall (WTC, 1983).

For the present study, the information about the amount of irrigation water supply was collected from watercourse of 53-RB. The crop evapotranspiration (ET) value was computed using the crop coefficients values given in the FAO-24 paper.

K. Agricultural productivity

Agricultural production performance indicators include cropping intensity, ratio of area planted and area harvested, annual yield, productivity of land and productivity of water (Rao, 1993) [21]. In the present study, an attempt has been made to estimate the productivity of water. Productivity of water or water use efficiency (WUE) is expressed in Equation (3).

$$WUE = \frac{CY}{WS} \tag{3}$$

where, CY is the crop yield and WS the water supplied.

L. Overlay Analysis

Overlay analysis of total water applied to the field, water use efficiency, organic matter and yield of rice and wheat crop was done. The overlay maps were prepared by using ArcMap. The data of the above mentioned parameters were added along with the latitude and longitude values of the field points. Afterwards the values of the individual parameter were interpolated to raster through inverse distance weighted in spatial analyst tool bar. Then the data was reclassified into three main classes and the raster data was converted to features and finally using layout command the maps were prepared and layout files were exported.

III. Results and Discussion

A. Irrigation Water Savings in wheat

Water savings were measured for each irrigation (1st, 2nd, 3rd and 4th) in terms of time saving for irrigating one acre of wheat with same stream size both for bed and conventional planting at various farm fields of site. The timings observed for each irrigation for bed and conventional planting helped to determine the percentage of water savings on bed-furrow and conventional planting systems. The water saving per acre varies from 46.51% to 56.5% of time among all four irrigations.

The disparity in water saving is due to various soil types, leveled and unleveled fields, sowing technique and farmers approach towards appropriate water application according to their crop water requirement. The average range of irrigation water saving at site was 51.37%. Table I gives the details of water supplied (min) and water saving (%).

B. Irrigation Water Savings in Rice Crop

The range of water saving is 28.91 to 45 % which happens due to over irrigation even in bed planting by same farmers. Table I gives the details of water supplied (min) and water saving (%).

C. Wheat Yield

At maturity of crop, wheat samples from $1m^2$ were collected, weighed and threshed for final grain yield. It was noticeable that the yield of the wheat crop was consistently larger in bed planting fields compared with the conventionally broadcast fields. The percentage yield increase in the bed planting fields varies from 11.83 to 29.4 % under varying soil and crop conditions observed at different farms. The higher yield under bed planting could be due to balanced water supply, favorable soil conditions at the beds, more root growth, more sunlight utilization by the plants, balanced plant to plant distance, better weed control and lesser lodging etc. It was evident that careful and timely applications of inputs increased the yield of the crop and the results suggested that farmers have yet a great opportunity for increasing crop growth without major changes in inputs rather they could achieve higher outputs by practicing time management in field operations. The results are encouraging and supported for adoption of bed planting technology at larger scale. Table II shows the yield values at each farm.

D. Rice Yield

It is obvious from the data that all the cultivars of rice performed better on bed furrow system in comparison with traditionally flooded flat fields. Highest percent increase in yield of rice in bed planted rice was observed as 29.4% while comparing it with the traditional sowing technique. Minimum percent increase of rice yield of bed planted field was obtained as 12.45 %. Results showed that overall increase of 26.3 % was obtained from bed planted rice in comparison with traditionally flooded fields of rice. Table II shows the yield values at each farm.

E. Adequacy

The adequacy of water supply to various fields was characterized by estimating RWS for each distributary for the rabi season of 2008-2009 and kharif season of 2009. Values of RWS ranged from 0.525 to 0.611 in wheat bed system while in flat system it ranges from 0.66 to 0.76. In rice bed and flat system it ranges from 0.85 to 1.07 and 0.85 to 1.09, respectively. This indicated that farmers in the canal command areas generally tend to over-irrigate (Ray et al., 2002). The command areas have been classified into two categories, i.e. adequate water (0:9 < RWS < 1:1) and water deficit (0:5 < RWS < 0:9). This supported the general impression that the water in canals does not reach the tail end. Table II shows the values of RWS at each farm.

F. Water Use Efficiency

The agricultural productivity or the efficiency of water to produce crop growth has been computed from Equation 3.5. The efficiency ranges from 14.5 to 33.54 kg/ha/mm in wheat (bed and flat) and from 3.49 to 10.05 kg/ha/mm in rice crop (bed and flat). Table II shows the values of WUE at each farm.

G. Overlay Analysis

i. Overlay of Yield and Organic matter

According to the Fig. 1, farm no. 2, 10, and 11 comes under the range of low organic matter (0.19-0.38), while four farms comes under the range of medium organic matter (0.38-0.57) and ten out of seventeen comes under the range where organic matter is highly valued (0.57-0.76). According to the fig. wheat yield on flat bed out of seventeen two comes under the category of low yield (3347.16-3984.90 kg/ha), eleven under medium yield range (3984.90-4622.65 kg/ha) and four under high yield range (4622.65-5260.39 kg/ha). However, the lowest yield on flat bed is less than the average and high yield is higher than the average value of wheat grown in Pakistan (i.e. 4000-4500 kg/ha).

Similarly, in wheat yield on raised bed (Fig. 2) out of seventeen two comes under the category of low yield (4569.13-5048.95 kg/ha), twelve under medium yield range (5048.95-5528.77 kg/ha) and three under high yield range (5528.77-6008.60 kg/ha). However, the lowest yield on raised bed is greater than the average value of wheat (i.e. 4000-4500 kg/ha) grown in Pakistan recommended by the Agriculture Department of the country. One of the farmer namely Naqsh Band have medium range of organic matter but low yield and similarly, six farmers that comes under the category of high organic matter have medium yield.

In Fig. 3, three farmers come under the category of low yield (3347.47-4042.67 kg/ha), ten under medium yield range (4042.67-4737.87 kg/ha) and four under high yield range (4737.87-5433.07 kg/ha) of rice on flat bed. However, the lowest yield on flat bed is less than the average and high yield is higher than the average value of rice grown in Pakistan (i.e. 4000-4500 kg/ha).

In Fig. 4, three farmers come under the category of low yield (4570.01-5285.04 kg/ha), eleven under medium yield range (5285.04-6001.27 kg/ha) and three under high yield range (6001.27-6716.69 kg/ha) of rice on raised bed. However, the lowest yield on raised bed is greater than the average value of rice (i.e. 4000-4500 kg/ha) grown in Pakistan recommended by the Agronomy Department of University of Agriculture, Faisalabad).

TABLE I
WATER SAVING DATA

Farm No.	Farmers name	Area under wheat and rice crop (ha)		Total Irrigation time in Wheat (min)								Total 15 Irrigation time in Rice (min)		Irrigation water saving in wheat bed in comparison of flat system (%)				Irrigation water saving (%) in raised bed in comparison of flat irrigation system
		Bed	Flat	1st Irrigation		2nd Irrigation		3rd Irrigation		4th Irrigation				1st Irrigation	2nd Irrigation	3rd Irrigation	4th Irrigation	
				Bed	Flat	Bed	Flat	Bed	Flat	Bed	Flat	Bed	Flat					
1	Abdul Ghafoor	1.619	0.4047	85	172	65	140	110	230	110	220	1590	2875	50.58	53.57	52.17	50	45
2	Munir Ahmed	1.214	0.4047	82	165	71	150	120	235	115	235	2064	2888	50.3	52.67	48.93	51.06	30
3	Safdar	1.62	0.4047	91	188	64	147	105	215	116	225	1855	2810	51.59	56.46	51.16	48.44	34
4	Haji Sahab	1.619	0.4047	81	160	69	148	115	230	120	230	1747	2675	49.38	53.38	50	47.82	34.68
5	Javed Iqbal	2.428	0.4047	85	165	72	142	105	230	110	225	1875	2645	51.5	49.3	54.3	51.1	29.1
6	Matloob Hussain 1*	2.024	0.4047	80	165	68	140	110	225	110	230	1821	2791	51.5	51.4	51.1	52.2	34.75
7	Matloob Hussain 2*	2.024	0.4047	85	168	65	153	105	221	116	235	1815	2770	49.4	57.51	52.49	50.63	35
8	Matloob Hussain 3*	2.428	0.4047	87	170	70	149	109	225	115	220	1890	2880	48.82	53.02	51.56	47.72	34.4
9	Matloob Hussain 4*	1.416	0.4047	83	165	72	155	112	217	105	218	1899	2890	49.69	53.55	48.38	51.83	34.29
10	M. Shafique 1*	2.428	0.4047	80	175	60	142	105	230	100	230	1787	2675	51.4	57.7	54.3	56.5	33.19
11	M. Shafique 2*	0.405	0.4047	90	195	76	152	109	217	112	230	1906	2907	53.84	50	49.77	51.3	34.43
12	Akhtar Naseem 1*	1.619	0.4047	80	180	70	158	107	228	105	215	1910	2865	55.55	55.69	53.07	51.16	34
13	Akhtar Naseem 2*	1.012	0.4047	82	160	72	159	110	225	115	215	1770	2490	48.75	54.71	51.11	46.51	28.91
14	Naqsh Band	1.012	0.4047	83	162	69	141	113	215	120	240	1891	2789	48.76	51.06	47.44	50	32.19
15	Shoukat 1*	1.619	0.4047	93	200	71	152	115	220	119	225	1995	2970	53.5	53.29	47.72	47.11	33
16	Shoukat 2*	0.405	0.4047	81	170	68	145	118	232	110	215	1985	2864	52.35	53.1	49.13	48.83	30.69
17	Zafar Iqbal	1.619	0.4047	80	165	70	150	120	235	115	230	2040	2915	51.51	53.33	48.94	50	30
Average		1.56	0.4047	84	172	69	148	111	225	112	226	1873	2806	51.08	53.51	50.68	50.13	33.39

TABLE II
YIELD, WUE AND RWS DATA

Farm No.	Farmers name	Location of fields	Area under wheat and rice crop (ha)		Crop yield (kg/ha)				Water Use Efficiency (WUE) (kg/ha/mm)				Relative Water Supply (RWS)			
					Wheat		Rice		Wheat		Rice		Wheat		Rice	
			Bed	Flat	Bed	Flat	Bed	Flat	Bed	Flat	Bed	Flat	Bed	Flat	Bed	Flat
1	Abdul Ghafoor	Middle	1.62	0.40	5335	4246	6300	4740	29.6	14.84	10.05	4.87	0.595	0.74	0.89	1.08
2	Munir Ahmed	Middle	1.21	0.40	5642	4397	4837.1	3412.9	30.48	15.04	6.41	3.49	0.611	0.76	1.07	1.09
3	Safdar2*	Middle	1.62	0.40	5423	4237	5680	4163	29.82	14.63	8.13	4.35	0.601	0.75	0.99	1.06
4	Haji sahib	Middle	1.62	0.40	5251	4349	5730.4	4544.8	28.49	15.11	8.56	4.94	0.609	0.75	0.95	1.02
5	Javed Iqbal	Middle	2.43	0.40	5165	4348	5434	4742.4	28.57	15.2	7.72	5.2	0.597	0.74	1	1.01
6	Matloob Hussain1*	Middle	2.02	0.40	5364	4655	6718.4	5434	29.85	16.3	9.74	5.71	0.594	0.74	0.98	1.06
7	Matloob Hussain2*	Middle	2.02	0.40	5680	4163	5822.9	4176	31.47	14.35	8.47	4.42	0.596	0.75	0.97	1.05
8	Matloob Hussain3*	Middle	2.43	0.40	6009	5261	5434	4940	32.8	18.35	7.67	5.06	0.605	0.74	1	1.08
9	Matloob Hussain4*	Middle	1.42	0.40	5291	4140	5335.2	4248.4	29.27	14.57	7.51	4.34	0.597	0.74	1	1.09
10	M. Shafiq1*	Tail	2.43	0.40	5329	4472	5437	4349	33.54	17.38	8.99	5.39	0.525	0.67	0.86	0.9
11	M. Shafiq2*	Tail	0.40	0.40	4837	3412	5291	4140	28.72	13.07	8.38	4.82	0.556	0.68	0.89	0.96
12	Akhtar Naseem1*	Tail	1.62	0.40	5434	4742	6160	4623	33.39	18.37	9.74	5.44	0.538	0.67	0.89	0.94
13	Akhtar Naseem2*	Tail	1.01	0.40	5335	4248	5335.2	4248.4	32.02	16.78	8.88	5.56	0.55	0.66	0.85	0.85
14	Naqsh Band	Tail	1.01	0.40	4569	3347	5642	4397	27.2	13.23	8.98	5.28	0.555	0.66	0.89	0.93
15	Shoukat1*	Tail	1.62	0.40	5274	4170	4569.5	3347	30.85	15.93	7.01	3.83	0.565	0.68	0.92	0.97
16	Shoukat2*	Tail	0.40	0.40	5249	4628	4729	3421	31.59	18.23	7.28	4.03	0.549	0.66	0.92	0.94
17	Zafar Iqbal	Tail	1.62	0.40	5261	4351	5538.7	4212.8	31.32	16.87	8.36	4.89	0.555	0.67	0.94	0.96
Average			1.56	0.40	5320	4304	5529	4302	30.53	15.78	8.35	4.80	0.58	0.71	0.94	1.00

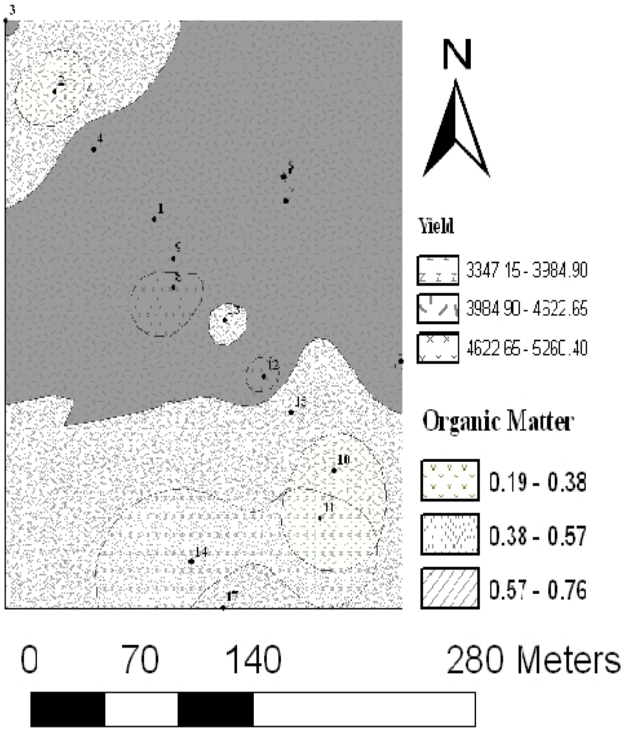

Fig. 1 Overlay map of organic matter (%) and Wheat yield (kg/ha) on flat bed

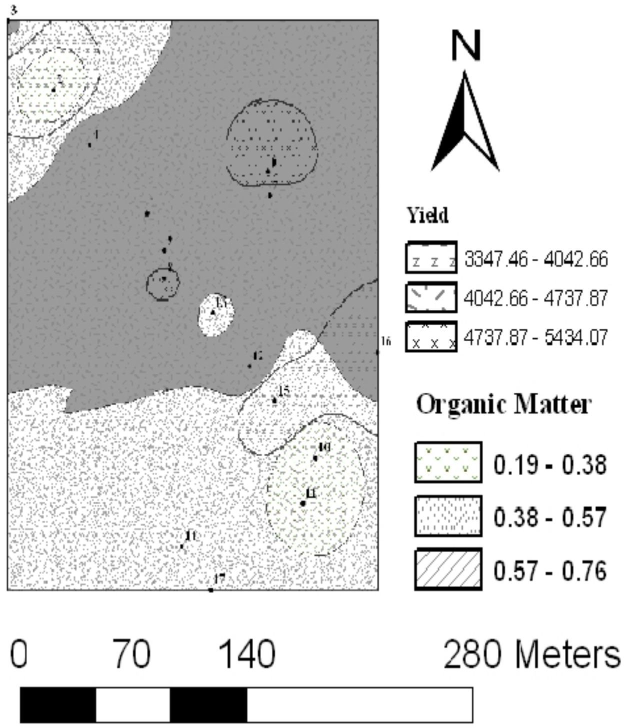

Fig. 3 Overlay map of organic matter (%) and Rice yield (kg/ha) on flat bed

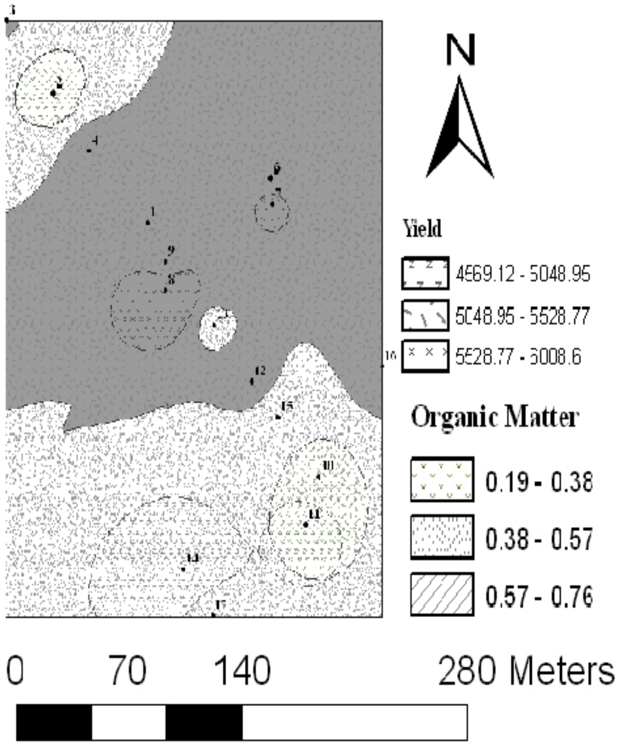

Fig. 2 Overlay map of organic matter (%) and Wheat yield (kg/ha) on raised bed

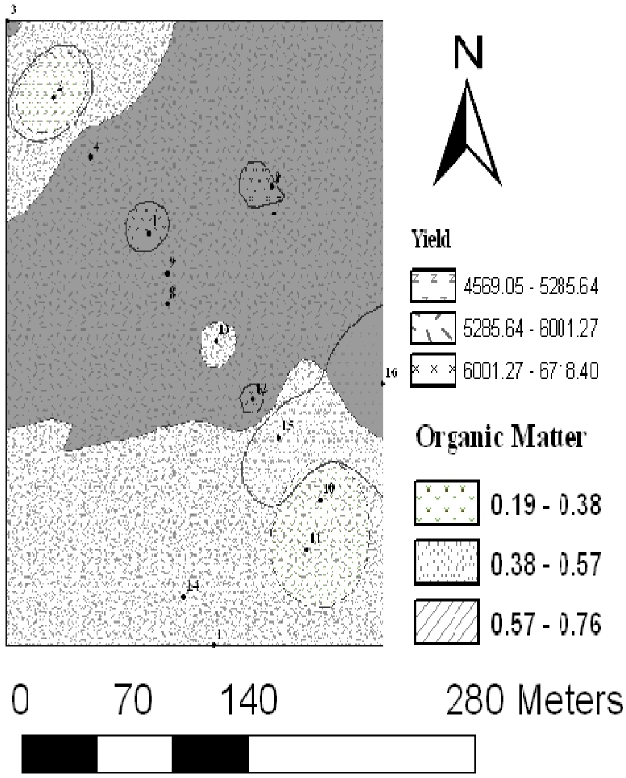

Fig. 4 Overlay map of organic matter (%) and Rice yield (kg/ha) on raised bed

ii. Overlay of Yield and Total Water Applied

According to Fig. 5, eight farmers comes under the range of lowest water applied (252.94-266.07 mm) and nine out of seventeen comes under the range where water supplied is highly valued (266.07-279.19 mm) in wheat crop on flat bed. The value of water supplied to flat bed in wheat crop is much more than supplied on raised bed whereas, the yield produced is less as compare to raised bed. According to map, medium yield (3984.90-4622.65 kg/ha) is produced where less water was supplied in case of four farms i.e. 10, 13, 15 and 17. While high yield (4622.65-5260.39 kg/ha) is produced where less water was supplied in case of farm no. 12 and 16. The reason of high yield might be the high percentage of organic matter in the soil as compared to other fields.

Similarly, in Fig. 6, five farms comes under the range of lowest water supplied (158.87-167.61 mm), while four farms comes under the range of medium water supplied (167.61-176.35 mm) and seven out of seventeen farms comes under the range where water supplied is highly valued (176.35-185.09 mm) in wheat crop on raised bed. Less wheat yield (4569.13-5048.95 kg/ha) is produced where the water supplied is medium ranged in case of two farms i.e. 11 and 14, while medium yield (5048.95-5528.77 kg/ha) is produced where less water was supplied in case of farm no. 10 and 13.

In Fig. 7, three farms comes under the range of lowest water applied (764.71–835.91 mm), six in the range of medium water supplied (835.91-907.02 mm) and eight comes under the range where maximum water was supplied (907.02-978.15 mm) in rice crop on flat bed. The value of water supplied to flat bed in rice crop is much more than supplied on raised bed whereas, the yield produced is less as compare to raised bed. According to map, less yield (3347.47-4042.67 kg/ha) and medium yield (4042.67-4737.87 kg/ha) is produced where maximum water was supplied in case of farm no. 2, 15 and 16 respectively. The reason of fewer yields is the less percentage of organic matter in the soil as compared to other fields.

Similarly, in Fig. 8, eight farmers comes under the range of lowest water supplied (600.72-651.18 mm), one in the range of medium water applied (651.18-703.60 mm) and eight comes under the range where maximum water was supplied (703.60-755.06 mm) in rice crop on raised bed. According to map, less yield (4570.01-5285.04 kg/ha) is produced where maximum water was supplied in case of farm no. 2. The reason of fewer yields might be the less percentage of organic matter in the soil as compared to other fields. High yield (6001.27-6716.69 kg/ha) is produced where less water was supplied incase of farm no. 1 and 12.The reason of high yield might be the high percentage of organic matter in the soil as compared to other fields.

iii. Overlay of Water use efficiency and Total water supplied

According to the Fig. 9, five farms comes under the range of lowest water use efficiency (13.07-14.84 kg/ha/mm) and six have medium WUE (14.84-16.6 kg/ha/mm) and six comes under the range where WUE is high (16.6-18.37 kg/ha/mm) in wheat crop on flat bed. According to map, less water use efficiency is recorded where maximum water was supplied and high water use efficiency is calculated where low water was supplied incase of five farms.

Similarly, in Fig. 10, three farms comes under the range of lowest water use efficiency (27.20-29.31 kg/ha/mm), while eight farms comes under the under the range of medium water use efficiency values (29.31-31.43 kg/ha/mm) and six out of seventeen comes under the range where high water use efficiency (31.43-33.54 kg/ha/mm) in wheat crop on raised bed. Less water use efficiency is seen incase where maximum water was supplied and high water use efficiency is calculated where low water was applied.

Similarly, in Fig. 11, five farms were recorded as having lowest WUE (3.49-4.23 kg/ha/mm). Seven farms come under the range of medium WUE (4.23-4.97 kg/ha/mm) and remaining seven comes under the range where maximum WUE was recorded (4.97-5.71 kg/ha/mm) in rice crop on raised bed. According to map, six farmers are recorded as having high WUE whereas, the water supplied to the field was of minimum range.

In Fig. 12, four farms were recorded as having lowest WUE (6.41-7.62 kg/ha/mm). Seven farms come under the range of medium WUE (7.62-8.84 kg/ha/mm) and remaining six comes under the range where maximum WUE was recorded (8.84-10.05 kg/ha/mm) in rice crop on raised bed.

H. Statistical analysis

Table III & IV shows the statistical analysis of organic matter, Total water supplied to both crops in bed and flat system, yield and WUE.

TABLE III
STATISTICAL ANALYSIS

Parameter	Statistical Analysis		
	Mean	Standard Deviation	Skewness
Organic Matter	0.54471	0.17285	-0.73877
Total water supplied in wheat (flat)	273.22	16.001	-0.13798
Total water supplied in wheat (bed)	174.48	8.5179	-0.317
Total water supplied in rice (flat)	899.45	67.113	-0.35275
Total water supplied in rice (bed)	665.4	42.544	0.2733
Wheat yield in flat	4303.9	444.84	-0.40382
Wheat yield in bed	5320.5	313.41	-0.27919
Rice yield in flat	4302.3	547.8	-0.13495
Rice yield in bed	5529.1	545.87	0.26629
WUE in wheat flat	15.779	1.6817	0.15221
WUE in wheat bed	30.528	1.8224	0.065425
WUE in rice flat	4.8012	0.63555	-0.50878
WUE in rice bed	8.3459	1.0068	-0.059573

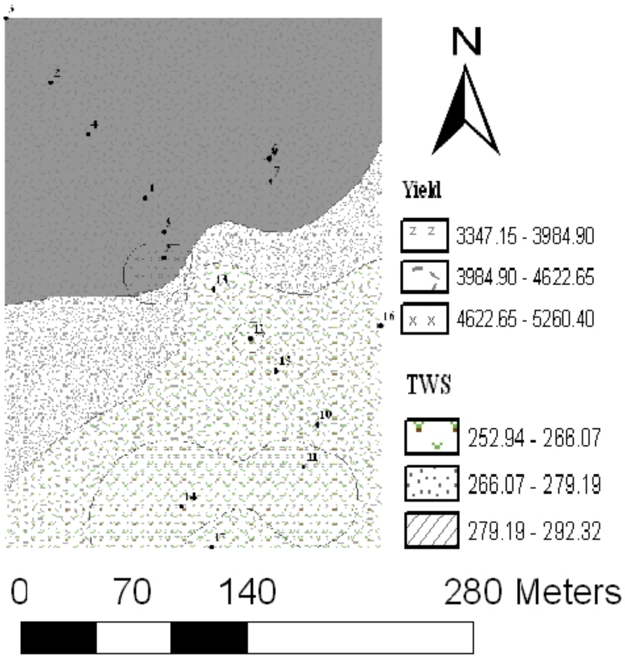

Fig. 5 Overlay map of total water applied (mm) and Wheat yield (kg/ha) on flat bed

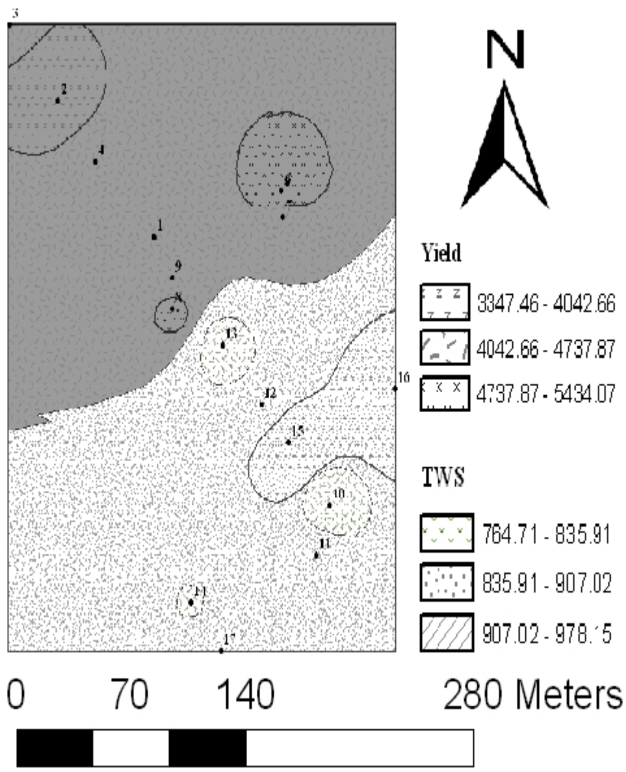

Fig. 7 Overlay map of total water applied (mm) and Rice yield (kg/ha) on flat bed

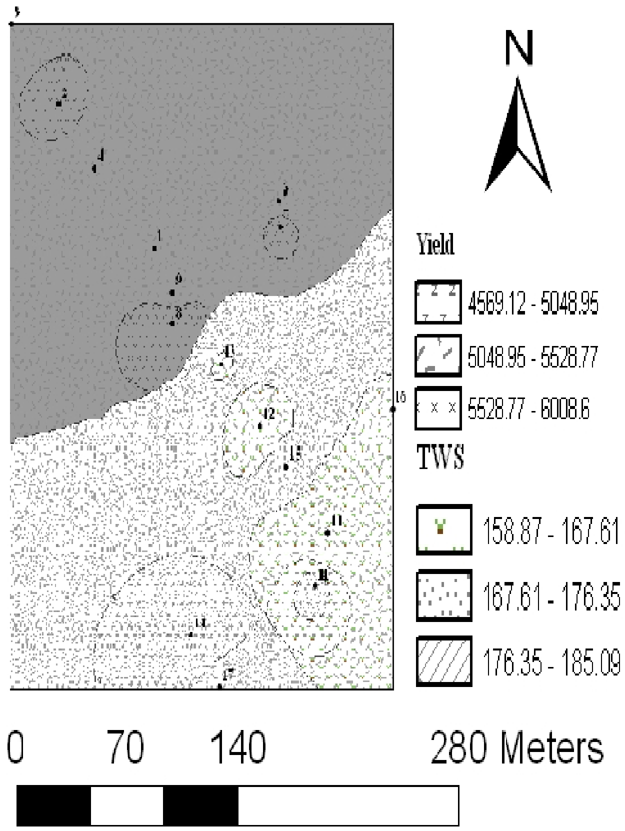

Fig. 6 Overlay map of total water applied (mm) and Wheat yield (kg/ha) on raised bed

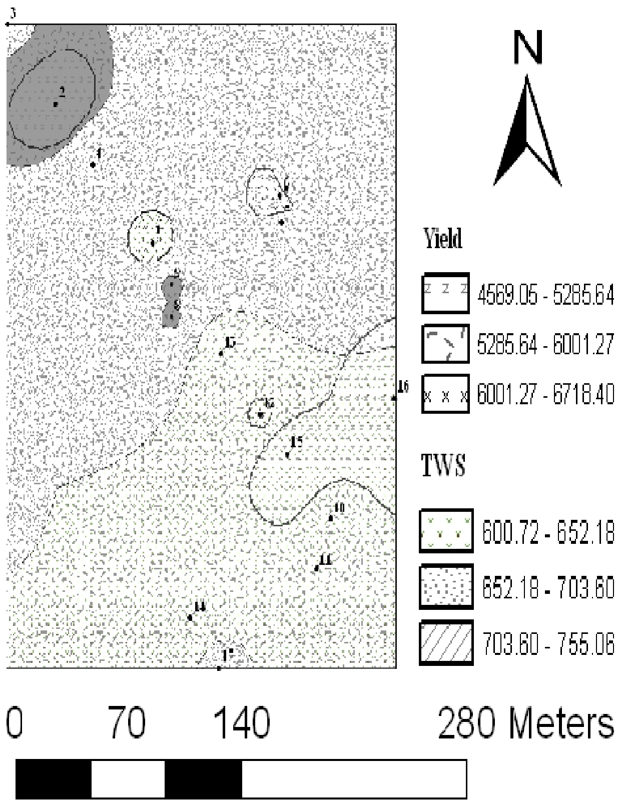

Fig. 8 Overlay map of total water applied (mm) and Rice yield (kg/ha) on raised bed

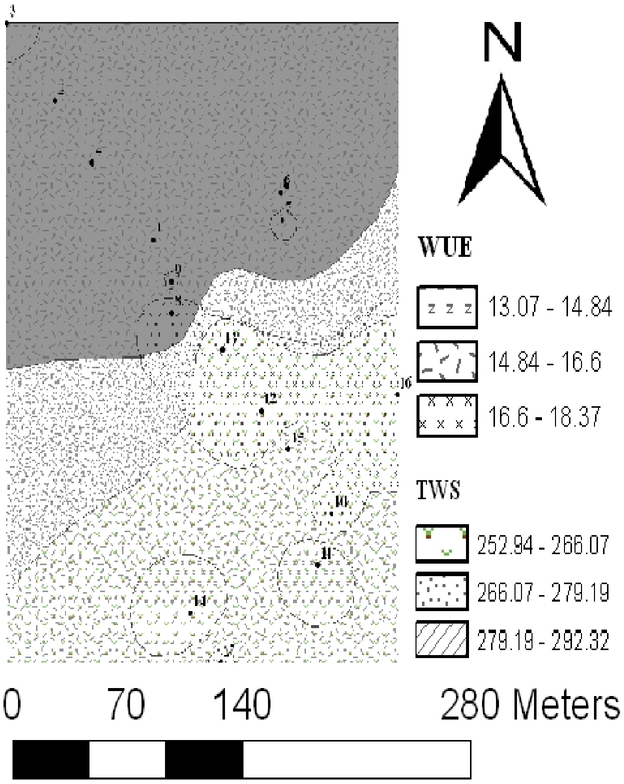

Fig. 9 Overlay map of total water supplied (mm) and WUE (kg/ha/mm) to wheat (flat bed)

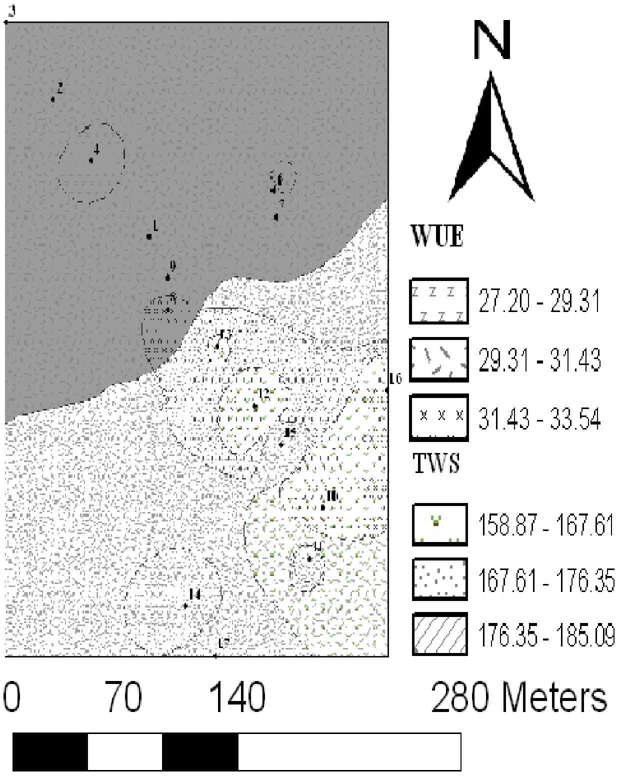

Fig. 10 Overlay map of total water supplied (mm) and WUE (kg/ha/mm) to wheat (raised bed)

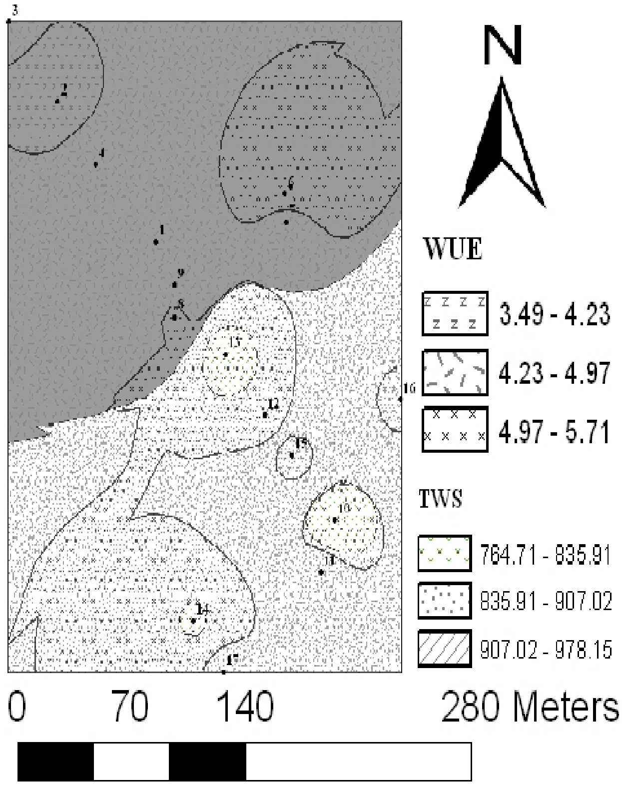

Fig. 11 Overlay map of total water supplied (mm) and WUE (kg/ha/mm) to rice (flat bed)

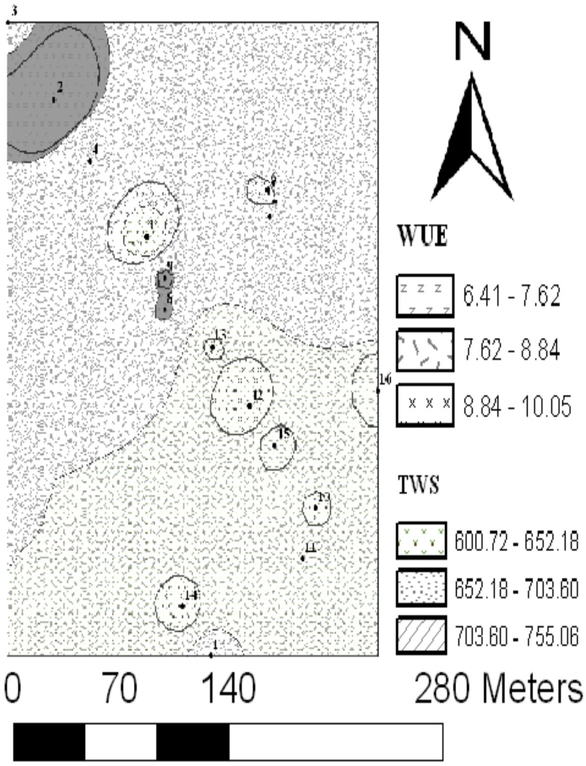

Fig. 12 Overlay map of total water supplied (mm) and WUE (kg/ha/mm) to rice (raised bed)

TABLE IV
SKEWNESS AND MEAN FACTORS

Skewness factor									
Crop		Wheat bed		Wheat flat		Rice bed		Rice flat	
In put	Organic matter	-0.73877	Negative skewness, less symmetrical	-0.73877	Negative skewness, less symmetrical	-0.73877	Negative skewness, less symmetrical	-0.73877	Negative skewness, less symmetrical
	Total water supply	-0.317	Negative skewness, less symmetrical	-0.13798	Negative skewness, more symmetrical than bed	0.2733	positive skewness, less symmetrical	-0.35275	Negative skewness, less symmetrical than bed
Out put	yield	-0.27919	Negative skewness, less symmetrical	-0.40382	Negative skewness, less symmetrical than bed	0.26629	positive skewness, less symmetrical	-0.13495	Negative skewness, less symmetrical than bed
	Water use efficiency	0.065425	positive skewness, near to symmetry	0.15221	positive skewness, less symmetrical than bed	-0.059573	Negative skewness, near to symmetry	-0.50878	Negative skewness, very less symmetrical
Mean factor									
Crop		Wheat bed		Wheat flat		Rice bed		Rice flat	
In put	Organic matter	0.54471		0.54471		0.54471		0.54471	
	Total water supply	174.48	Less water applied than flat system	273.22	More water applied than bed system	665.4	Less water applied than flat system	899.45	More water applied than bed system
Out put	yield	5320.5	More yield than flat	4303.9	Less yield than bed	5529.1	Less yield than bed	4302.3	More yield than flat
	Water use efficiency	30.528	More efficient than flat	15.779	Less efficient than bed	8.3459	More efficient than flat	4.8012	Less efficient than bed

IV. CONCLUSION

The overall impact of the Khurrianwala distributary has been increased two to three-fold in the gross cropped area and average crop yield and the generation of a high net additional income for the region. However, in the last 40 years, there has been an increase in the problems of water logging and salinity [15]. This has been due to non-uniform distribution system of irrigation water. The water supplied is also not equitably distributed, the head getting more than the tail end. It has also been found that a greater application of water does not result in higher crop vigor. Less water supplied to bed is more affective as its WUE value is higher than flat system where more water is supplied in both seasons. Similarly, RWS values show that maximum water deficit while minimum area is getting adequate water supply. Greater yield is recorded in bed system as plant per square meter is more in bed system in comparison of flat system. Thus, the integration of GIS tools to regularly compute performance indices could provide irrigation managers with the means for managing efficiently the irrigation system.

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