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Technical Performance Evaluation of Ketar Medium Scale Irrigation Scheme, Southeast of Oromia Regional State, Ethiopia

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Abstract
Evaluation of performance of irrigation systems has been increasingly stressed in recent years by many researchers and managers of irrigation schemes. This study was aimed to contribute to the improvement of irrigation efficiency and crop productivity of the farm. It had been conducted on Ketar medium scale irrigation scheme situated in Arsi zone Oromia Regional State of Ethiopia. Performance indicators used were conveyance, application, storage efficiency, water application uniformity; depletion fraction, runoff ratio, deep percolation, irrigation water use efficiency and scheme sustainability were done. Potato was the selected crop for the experiment. Soil of the study area was found clay loam, moderate acidic, non-saline soil and has 3.44 OM in average. Average E_c, E_a, E_u, E_s, DF, RR, DPF, IWUE of Ketar scheme was found as 57.4% , 61.6%, 61.6%, 160%, 70.1%, 27.86%, 10.54% and 2.38kg/m^3, respectively. The study was concluded as upper and middle stream users were consuming more water than the lowers with decreased productivity of the scheme and technical support and SWC activities in this watershed and redesign are recommendable for sustained design discharge.

1. Introduction

Low level of performance can be identified at any level and stage of irrigation systems. At system level, the status of cropping intensity and yields from many irrigated areas are usually unsatisfactory. These low performances occur in irrigation though it is a technological package that feeds billions of people. Good performance is not only a matter of high output, but also one of efficient use of available resources (Rust and Snellen, 1993). Improper irrigation practices lead to inefficient water distribution, non uniform crop growth, and excess leaching in some areas and insufficient leaching in others, all of which decrease the yield per unit of land area against per unit of water applied (Strelkoff *et al.,* 1999). Evaluation of performance of irrigation systems has been increasingly stressed in recent years by many researchers and managers of irrigation schemes. In the field of irrigation system management, performance evaluation of irrigation system is the key issue (Seleshi *et al.,* 2010).

Hence, this study was planned to undertake with the general objective of evaluating the performance of Ketar medium scale irrigation scheme that is one of onion and potato producing farms in Arsi zone of Oromia Regional State. The specific objectives of the study were evaluating surface irrigation efficiency of Ketar medium scale irrigation scheme and determining the level of water productivity of the farm on which performance evaluation would be conducted using Potato as a representative crop.

2. Materials and Methods

2.1. Description of Study Area

The study has been conducted on Ketar medium scale irrigation scheme situated in Tiyo woreda of Arsi zone Oromia Regional State of Ethiopia. It feeds Abosera Alko, Ketar Genet and Hamsa Gasha kebeles. Average annual temperature is 13.8°C. The average annual rainfall of the woreda is 1118 mm. The woreda has an altitude of 2430m above sea level (asl) (Yazachew and Kasahun, 2011).

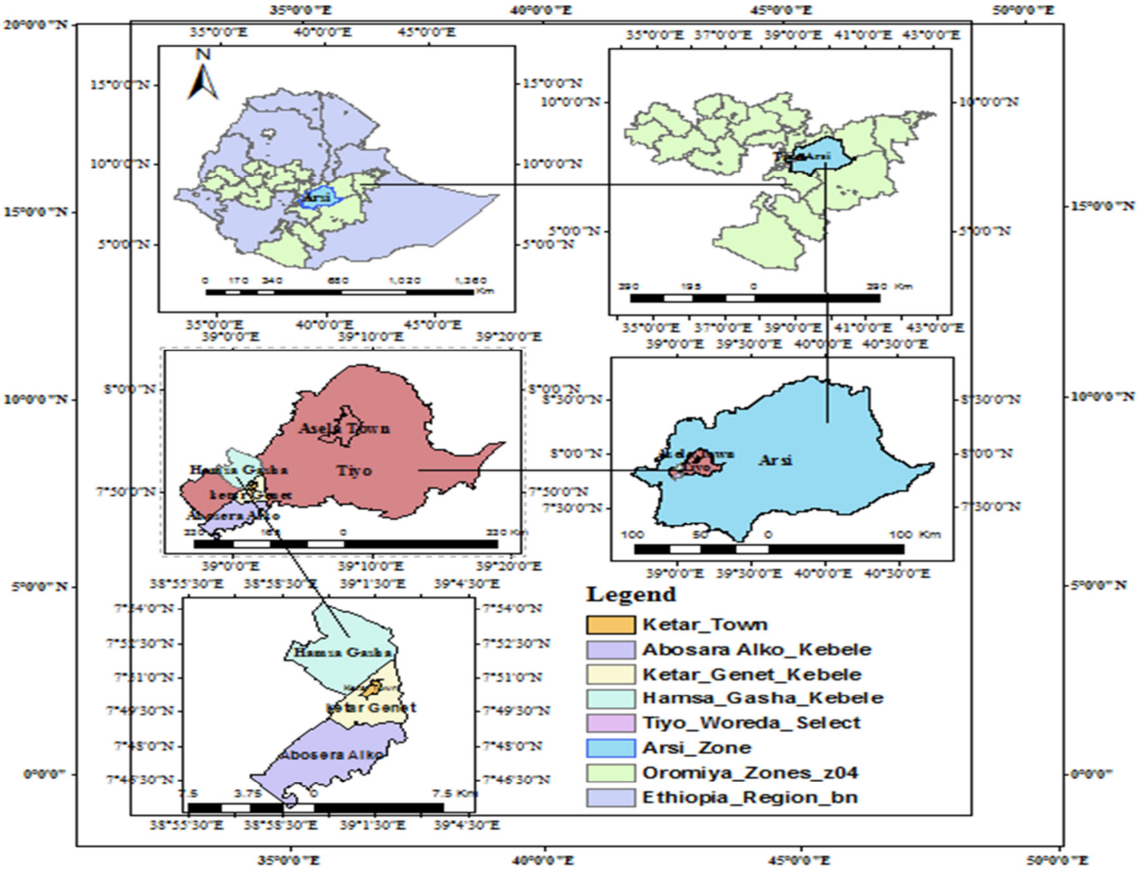

Figure 1. Location Map of Study Area

2.2. *Field Layout*

Potato crop was selected for the experiment for selected plots. Experimental design was based on completely randomized complete block design (RCBD) type.

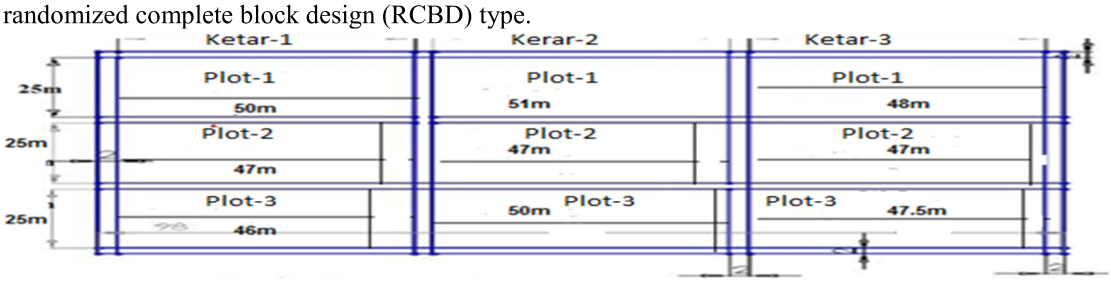

Figure 2. Experimental Field layout

2.3. *Soil Sampling*

Double ring infiltrometer of diameter 60cm (outer ring) and 30cm (inner one) was used to measure soil infiltration. Hydrometer method was used for analyzing particle size distribution and USDA textural triangle (USDA, 1972) was used to identify the textural class. Organic matter content of the soil was determined by titration method. Soil pH was determined by using water suspension with soil to water ratio 1:2.5 by pH meter. EC was determined by method of water suspension with soil to water ratio 1:2.5 by electro conductivity meter. Undisturbed soil samples were collected by core sampler and taken to dry oven at 105°C for 24hr to determine bulk density (Hillel, 2004). $\rho_b = \frac{M_s}{V_t}$ (2.1)

Where: ρ_b = soil bulk density (gm/cm^3), M_s=mass of dry soil (gm) and V_t=total volume of soil in the core sampler (cm^3)

2.4. *Crop Water Requirement (CWR) and Irrigation Water Requirement (IWR)*

Necessary climatic data was processed to CROPWAT version-8 to calculate the reference evapotranspiration

(ET_o) of the study area using data of Chebi meteorological Station and National Meteorological Agency. ET_c was computed as shown in equation 3.2. Then CWR and IWR were computed. $ET_c = ET_o x K_c$ (3.2)

where, ET_c = crop evapotranspiration (mm/day), ET_o = reference crop evapotranspiration (mm/day), K_c = crop coefficient, Irrigation interval was calculated as;

2.5. *Inflow and outflow water measurements at field*

Discharge measurements at selected points were done by current meter, structures (trapezoidal and rectangular weir) and three inch Parshall flume (at field channel).For 3 inch Parshall flume, $Q = 0.1771H^{1.550}$ (2.3) and $V_a = Q * \Delta t$ (2.4)

where; H=water level height in Parshall flume (m), Q= discharge through the flume (l/s), V_a= total volume of water applied (m^3), Δt =flow time to the field (seconds)

2.6. *Gravimetric sampling*

Moisture status of the soil profile for each field was measured before and after each irrigation event. Moisture has been calculated as a percentage of dry weight of the soil sample (ϑ_m) using the following formula,

$$\vartheta_m = \frac{M_t - M_s}{M_s} * 100 = \frac{M_w}{M_s} \% * 100 \qquad (2.5)$$

where, ϑ_m = soil moisture status in weight basis (%), M_t=weight of fresh sample (gm), W_s=weight of over dried sample (gm)

Volumetric moisture content (θ_v) has been calculated using as, $\theta_v = \vartheta_m * \frac{\rho_b}{\rho_w}$ (2.6)

where, θ_v =volumetric moisture content (%), ρ_w = unit weight of water (gm/cm^3)

2.7. *Total Available Water (TAW)*

Required amount of water for each irrigation event was measured using the water balance approach. TAW was computed as, $TAW = \frac{(FC - PWP)}{100} * BD * D$ (2.7)

where: TAW=total available water (mm), FC=field capacity (% by weight bases),PWP=permanent wilting point (% by weight bases), D=depth of root zone (mm), BD=specific density of soil (bulk density of soil) (gm/cm^3)

2.8. *Determination of Irrigation System Performance Indicators*

2.8.1. Irrigation efficiencies

2.8.1.1. Conveyance efficiency

It is expressed as: $E_c = \frac{V_f}{V_t} * 100$ (2.8)

where, E_c= Water Conveyance Efficiency (%), V_f= Volume of irrigation water that reaches the farm or field (m^3/s), V_t= Volume of irrigation water diverted from water source (m^3/s)

V_f was measured by Parshall flume for the nine plots and V_t was obtained by current meter to obtain mean velocity and processed to standard formula (Q=AxV).

2.8.1.2. Application efficiency

It is expressed as: $E_a = \frac{V_s}{V_f} * 100$ (2.9)

Where: E_a=Water application efficiency (%), V_s=Volume of irrigation water stored in the root zone (m^3/s or ha-m), V_f= Volume of irrigation water delivered to farm or field (m^3/s)

V_s was determined by calculating available water in the root zone in either volume bases or weight bases by determining soil moisture content before and two days after irrigation by gravimetric method for the nine selected plots

2.8.1.3. Application uniformity

It was expressed as: $D_u = \frac{D_{lq}}{D_{av}} * 100$ (2.10)

Where: D_u=Distribution Uniformity (%), D_{lq}=Average depth of water infiltrated in the low one-quarter of the field (m), D_{av} =Average depth of water infiltrated (m)

For computing D_{av}, moisture content of the field was measured before and after irrigation. Their difference and mean of their difference were calculated. For computing D_{lq}, moisture content of the field was measured before and after irrigation.

2.8.1.4. Water storage efficiency **(E_s)**

E_s is defined as the ratio of the volume of water stored in root to volume of water required filling the root zone to near field capacity and expressed as, $E_s = \frac{W_{ai} - W_{bi}}{W_{fc} - W_{bi}} * 100$ (2 .11)

Where: E_s=Soil water storage efficiency (%), W_{bi} =Weight of soil moisture before irrigation, W_{ai} = Weight of soil moisture after irrigation, W_{fc}=Weight of soil moisture at field capacity

W_{fc} in the crop root zone was determined from soil sample taken from the nine plots by using pressure plate apparatus. W_{bi} and W_{ai} was measured by taking irrigated soil sample from nine plots and drying it by oven for 24 hr at 105°c.

2.8.1.5. Irrigation water losses

i. Runoff ratio (R.R)

The amount of runoff from each field was collected and measured using known volumes of runoff collector buckets and Parshall flume was installed at the lower end of the field and runoff was calculated using the equation given by Walker (2003) as; $RR = \frac{D_r}{D_a} * 100$ (2.12)

Where: RR=runoff ratio (%), D_r=volume of runoff in terms of depth (mm), D_a=total depth of water applied to the field (mm)

ii. Deep percolation fraction (DPF)

Deep percolation fraction could be calculated indirectly from values of application efficiency (E_a) and runoff ratio (RR) as given by FAO (1989); DPF=100-E_a-RR (2.13)

2.8.2. Water productivity and relative irrigation supply of the scheme

Water productivity of the study area was determined from water applied to the farm throughout the growing season of the selected crop (Potato) and yield harvested from each plot.

It was computed using as, $IWUE = \frac{Y_a}{IW}$ (2.14)

Where: IWUE- irrigation water use efficiency (kg/m^3), Ya - actual yield (kg/m^2), IW - irrigation water applied (m^3/m^2)

2.9. Sustainability of Irrigation System

The simplest measure of sustainability is that quantifies the cumulative effect of negative impacts is "sustainability of irrigated area (SIA)" that was calculated by the expression given by Nelson (2002) cited by Awel (2009) as,

$$SIA = \frac{AC}{AI} \quad (2.15)$$

where: AC= current total irrigated area (ha), AI= total irrigated area when the system development way completed (ha), SIA =sustainability of irrigated area

2.10. Data Analysis

Collected data during the test of the system by using performance indicators were fed to Microsoft excel and was analyzed statistically. ANOVA of required comparison parameters were done by using SAS. Comparison of efficiency indicators of the stations were done by Least Significance Difference (LSD).

3. Results and Discussion

3.1. Scheme Characterization

The scheme has design discharge of 0.86m^3/s and observed discharge was 0.80m^3/s. Most of it has earthen canal which leads to seepage and deep percolation loss.

Table 1. Quantity and length of structures of Ketar scheme

No	Particular	Quantity	Length (m)
1	Irrigation pond	3	-
2	Main canal	1	11,713
3	Secondary canal	9	11,253
4	Tertiary canal	19	5,633
5	Area boundary	29	-
6	Farm boundary	3	-
7	Division box	16	

Table 2. Irrigated area and Users (H/H) of Ketar Irrigation Scheme rehabilitated by Community and OWRB with JICA cooperation (2000 E.C, 2008)

		Area (ha)			H/H		
Sub Station	Stations=>	Ketar–1	Keta-2	Ketar–3	Ketar–1	Keta-2	Ketar–3
1		16.11	27.24	11.29	45	56	43
2		23.61	21.96	10.46	67	45	15
3		13.61	42.52	14.88	38	88	40
4		15.06	11.48	5.76	43	24	17
5		10.57	15.27	6.63	31	32	11
6		11.46	17.80	4.78	32	36	11
7		12.61	15.63	3.70	33	32	25
8		-	14.18	9.37	-	29	18
9		-	16.49	10.68	-	34	42
10		-	18.82	12.38	-	39	53
11		-	-	10.22	-	-	43
12		-	-	16.13	-	-	52
Total		108.00	200.39	121.70	289	415	370

3.2. Crop Water Requirement and Irrigation Water Requirement

Average ET_c value of 19 years (1997-2015) of the study area was 4.43 mm/day for Potato from January-May at Chebi Meterological station. Net and gross irrigation requirement was 463.4mm for Potato from for one season (January to May).

Table 3. ET_c computation for Potato using CROWAT Model-8

Station : Chebi, Altitude: 1544m, Latitude: 7.83°, Longitude: 39.03°

Month	Decade	Growth Stage	Kc Coeff	ET_c mm/day	ET_c mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jan	2	Initial	0.5	2.13	17	4.7	11.2
Jan	3	Initial	0.5	2.18	24	9.7	14.2
Feb	1	Development	0.52	2.33	23.3	14.7	8.6
Feb	2	Development	0.72	3.26	32.6	18.3	14.3
Feb	3	Development	0.92	4.32	34.6	19.5	15.1
Mar	1	Mid	1.12	5.41	54.1	22.7	31.4
Mar	2	Mid	1.18	5.89	58.9	25.2	33.7
Mar	3	Mid	1.18	5.92	65.1	18	47.1
Apr	1	Mid	1.18	5.95	59.5	7.8	51.7
Apr	2	Mid	1.18	5.98	59.8	0.7	59.1
Apr	3	Late	1.13	5.69	56.9	2.3	54.6
May	1	Late	1	4.97	49.7	4.3	45.4
May	2	Late	0.86	4.26	42.6	4.7	37.9
May	3	Late	0.78	3.74	7.5	1.3	7.5
Average				4.43	41.83	10.99	30.84
Total					585.5	153.8	431.8

Under field conditions, potato water requirement is 350 to 650 mm during growing period, which is dependent on climate and cultivar. Estimated irrigation requirement for Ketar was 463.4, which was in the range of the one studied by Sood and Singh, (2003).

3.3 Inflow and Outflow Water Measurements at Field

Table 4. Discharge observed using 3'' Parshall Flume at field channel of selected farm

Station	Plot	Average Height (m)	Average Discharge (m^3/s) $*10^{-3}$	Average Irrigation Period (Sec)	Mean water applied at each Growth Stage (m^3)	Irrigation Frequency (days)	Total water delivered to farm (m^3)	Plot size (m^2)
Ketar-1	1	0.105	5.392	10800	58.23	14	843.56	1250
	2	0.098	4.850	9600	46.56	15	698.45	1175
	3	0.110	5.832	9300	54.24	17	922.04	1150
Ketar-2	1	0.085	4.254	8700	37.01	14	523.29	1275
	2	0.081	3.615	8900	32.17	19	608.51	1175
	3	0.077	3.311	10500	34.77	16	556.30	1250
Ketar-3	1	0.075	3.212	10080	32.38	16	518.04	1200
	2	0.072	3.016	9420	28.41	18	514.43	1175
	3	0.079	3.813	8820	33.63	18	617.40	1187.5
Average				9568.89	39.94	16	644.67	

3.4. Physico-Chemical Properties of Soil

Soil pH values indicated moderate acidic soil (5.31-5.88). It was concluded that the scheme soil was clay loam. According to Classes of salinity and EC (1 dS/m = 1 mmhos/cm; as adapted from USDA (1998), soil which has electrical conductivity 0<2 mmhos.cm is non-saline soil.

3.5. Soil Moisture Content and Bulk Density

From soil samples collected at depth of 0-30 and 30-60 cm, average soil moisture statuses were found as 34.90, 30.38 and 25.63% respectively for Ketar-1, Ketar-2 and Ketar-3. Bulk densities were found as 1.17, 1.10 and 1.09 g/m^3 for Ketat-1, Ketar-2 and Ketar-3 station respectively. Average bulk density of the scheme was found as 1.12 g/m^3.

3.6. Total Available Water (TAW)

Average total available water (TAW) for Ketar-1, 2 and 3 stations at 600mm depth were found as 79.25, 75.28mm and 71.05mm respectively. Average TAW of Ketar scheme was 75.

3.7. Irrigation Efficiencies

3.7.1. Conveyance efficiency (E_c)

Conveyance efficiencies were found as 66.86, 56.50 and 48.90% at Ketar-1, Ketar-2 and Ketar-3 main canals respectively. E_c of the scheme was estimated as 57.40%. As stated by FAO, (1989), for earthen canal length >2000m constructed on clay soil its E_c would be 80% where as 95% for lined canal. From that result it is concluded that E_c of Ketar scheme was poor.

3.7.2. Application efficiency (E_a)

Average application efficiency of the stations indicated that, it was in range of 57.19 and 65.51%. Average E_a of the scheme was 61.60%. Irrigation management can improve efficiency by 5-20% by applying the right depth of water in the right place at the right time (Rose, 2006). The result of plot one at Ketar-1 shows that there were runoff losses at the tail of furrows due to much water application which did not match with soil infiltration for clay soil, since soil of study area had lower value of infiltration rate. According to FAO (1989) E_a for surface irrigation is 60%. Based on this, Ketar-1 and was not efficient, where as Ketar-2 and 3 were efficient.

3.7.3. Application uniformity (D_u)

Application uniformities were found in range of 59.98 and 64.78. Average application uniformity of the scheme was 61.60. From those results, application uniformity among the stations were somewhat the same but different among plots. Operating the system at flow rates below or above the design flow rates could lead to inefficient and non-uniform applications as seen among plots.

3.7.4. Water storage efficiency (E_s)

From data collected and mean taken at three depths,(0-30, 30-45 and 45-60cm) average water E_s were 202.2 %, 141.3 % and 136.5% for Ketar-1, Ketar-2, and Ketar-3 respectively. It was 160.0 % for the scheme. According to Michael (2008), the importance of determining E_s is that, when water supplies are limited or when excessive time is required to secure adequate penetration of water into the soil.

3.7.5. Depletion fraction (DF)

An average depletion fraction of the scheme was 70.10%. Bos *et al.,* 2005 study indicated that decreasing depletion ratio (DR) would lead to rising ground water tables, which increased the risk of soil and ground water salinity. Therefore, deep percolation should be kept at lower value be on the safe side particularly for Ketar-1.

3.7.6. Irrigation water losses
The scheme has 27.86% mean runoff and 10.54% mean deep percolation. This indicates since the soil of the study area was clay and clay loam, its deep percolation was lower than runoff because there was lateral movement in addition to vertical flow of water in such type of soil.

3.7.7. Water productivity and relative irrigation supply of the scheme
Average productivity which was expressed by irrigation water use efficiency was 2.38 kg/m^3. According to Sood and Singh (2003), Potato requires 0.35 to 0.8 m^3 of water to produce 1 kg of tuber dry matter. This implies that water productivity is 1.25-2.86 kg/m^3. As Ketar scheme water productivity was 2.38 kg/m^3 it was in the range of study done by Sood and Singh (2003).

3.8 Sustainability of Irrigation System
From study conducted sustainability of the scheme was 1.26. Current command area is 26% greater than the designed one.

Table 9. Design and current command area of Ketar scheme

Station	Designed Command Area	Current command Area	Sustainability of Irrigation System
Ketar –1	109.00	143.00	1.31
Ketar –2	200.39	248.50	1.24
Ketar –3	121.70	150.00	1.23
Scheme	431.09	541.50	1.26

4. Summary, Conclusions and Recommendations
4.1. Summary and Conclusions
In this study, an attempt was made to evaluate the performance of Ketar medium scale irrigation scheme using irrigation performance indicators on the stations and three plots from each station. From the study the scheme has 57.40, 61.60, 61.60, 160.0, 27.86, conveyance efficiency, application, application uniformity, storage efficiency, runoff ratio were found and deep percolation fractions. Based on ANOVA test and LSD, there was significant difference among stations in irrigation water use efficiency at 5% and 10% significant level and there was no significance difference for other efficiency indictors at both significance levels. From study conducted farmers in upstream and middle stream were using excess water and siltation had affected night storage in downstream which caused shortage of water in addition to the influence of up and middle stream water users. There is also miss management of water as there are losses at different.

4.2. Recommendations
To reduce siltation problem of Ketar-3 night storage soil and to increase discharge of the scheme it is recommendable to do watershed management of the scheme by practices like soil and water conservation activities in the watershed in addition to newly designed reservoir. It is also recommendable to construct silt excluder at a point before water enters the reservoir to protect silt accumulation.

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Appedix Table **10**. Dimensions of structures and conveyance efficiency of Ketar scheme

Structure Place	Canal type	Canal shape	Top width (m)	Bottom width (m)	Water level width (m)	Water depth at left side (m)	Water depth at center (m)	Water depth at right side(m)	Average depth (m)	Discharge (m^3/s)	Conveyance Efficiency (E_c) (%)
Diversion weir	Lined	Trapezoidal	2.40	0.60	1.90	0.51	0.55	0.53	0.53	0.800	
Ketar-1 main canal	Earthen	Irregular	1.72	-	-	0.54	0.88	0.78	0.73	0.535	66.9
Ketar-1 secondary canal	Earthen	Irregular	0.80	-	-	-	-	-	-	0.202	-
Ketar-1 tertiary canal	Pipe 7.62cm)		-	-	-	-	-	-	-	-	
Ketar-2 main canal	Lined	Rectangular	2.00	2.00	1.66	0.57	0.59	0.58	0.58	0.452	56.5
Ketar-2 secondary canal	Lined	Rectangular	0.40	0.40	0.40	0.17	0.17	0.17	0.17	0.057	-
Ketar-2 tertiary canal	Earthen	Irregular	1.35			60	60	55			
Ketar-3 main canal	Lined	Rectangular	0.75	0.75	0.75	0.403	0.403	0.403	0.403	0.391	48.9
Ketar-3 secondary canal	Earthen	Irregular		-	135	60	60	55	58.33	0.106	-
Ketar-3 tertiary canal	Pipe	Circular Ø=8cm)									
Average Scheme E_c (%)											57.4

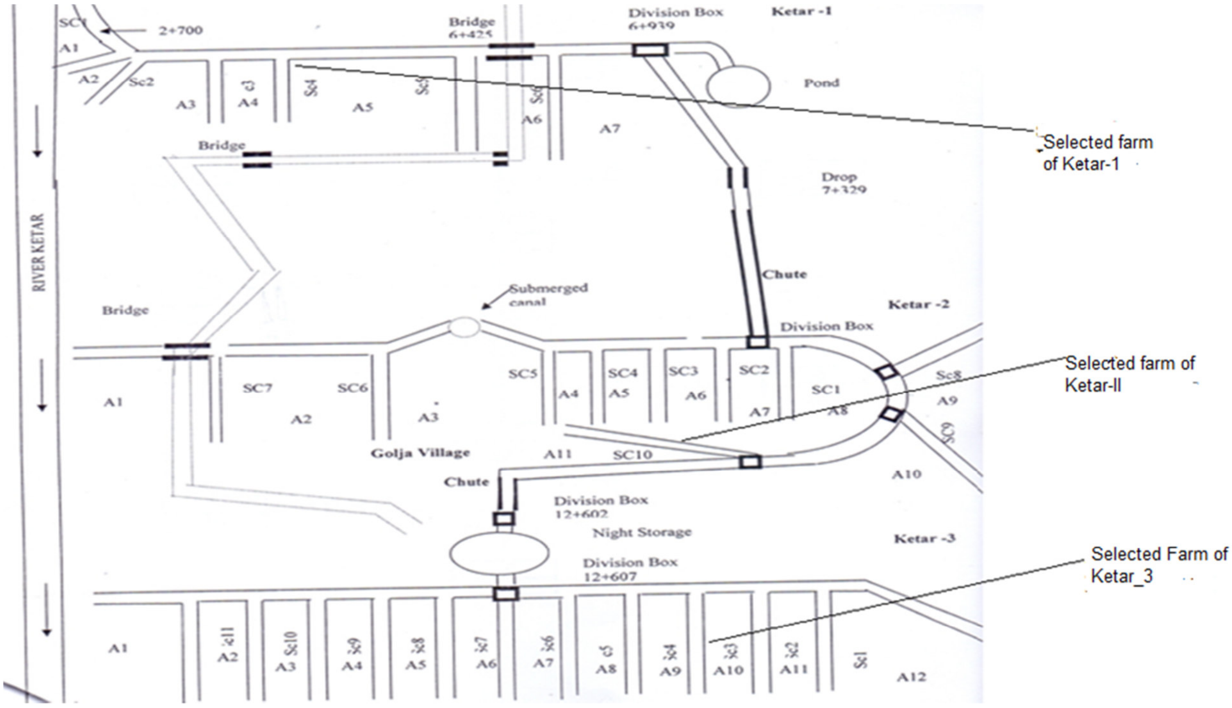

Figure 3. Layout of Ketar Irrigation Scheme Stations