

**TECHNICAL PERFORMANCE EVALUATION AND
REDESIGNING OF KETAR MEDIUM SCALE IRRIGATION
SCHEME, SOUTHEAST OF OROMIA REGIONAL STATE,
ETHIOPIA**

MSc THESIS

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HARAMAYA UNIVERSITY, HARAMAYA

**TECHNICAL PERFORMANCE EVALUATION AND
REDESIGNING OF KETAR MEDIUM SCALE IRRIGATION
SCHEME, SOUTHEAST OF OROMIA REGIONAL STATE,
ETHIOPIA**

**A Thesis Submitted through the School of Water Resources and
Environmental Engineering, Postgraduate Programs Directorate**

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MASTER OF SCIENCE IN IRRIGATION ENGINEERING**

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I hereby certify that I have read and evaluated this thesis entitled ‘Technical Performance Evaluation and Redesigning of Ketar Medium Scale Irrigation Scheme Southeast of Oromia Regional State, Ethiopia, prepared under my guidance by Dinka Fufa. I recommend that it be submitted as fulfilling the thesis requirement.

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Final approval and acceptance of the thesis is contingent upon the submission of the final copy of the thesis to the Council of Graduate Studies (CGS) through the candidate's Department Graduate Committee (DGC) of the Department of Irrigation Engineering.

DEDICATION

I dedicate this thesis work to my mother Ulfatu Fulea, my aunt Dawi Fulea and my cousin Dabesa Chaluma who grew me up and taught me how to stand firmly against challenge but were not lucky to see this success.

STATEMENT OF THE AUTHOR

By my signature below, I declare and affirm that this thesis is my bonafide research work. I have followed all ethical and technical principles of scholarship in the preparation, data collection, data analysis and compilation of this thesis. Any scholarly matter that is included in the Thesis has been given recognition in through citation.

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BIOGRAPHICAL SKETCH

The author was born on May 27, 1984, from his father Fufa Merera and his mother Ulfatu Fulea, in West Shewa Zone, Ambo Woreda, in village so called Dobi Daliti. He had followed his elementary education at Senkele Elementary School and Cheri Elementary School. He studied his high school and preparatory education at Ambo Senior Secondary School. After taking entrance examination of Ethiopian higher education he had joined Hawassa University in 2006. By the year 2010, he had completed his first degree and awarded BSc degree in Agricultural Engineering and Mechanization.

He has been employed at Oromia Agricultural Research Institute (OARI) and joined Asella Agricultural Engineering Research Center (AAERC), on Harvest and Post Harvest Research Team. After serving the institute for four years, he joined Haramaya University for his MSc education in Irrigation Engineering in 2014/2015 academic year.

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ACRONYMS AND ABBREVIATIONS

Asl	above sea level
ANOVA	Analysis of Variance
BD	Bulk Density
Cfb	Temperate Oceanic Climate
CSA	Central Statistical Agency
DF	Depletion Fraction
DMRT	Duncan Multiple Range Test
DPF	Deep Percolation Fraction
E_a	Application Efficiency
E_c	Conveyance Efficiency
E_s	Storage Efficiency
E_u	Application Uniformity
ET_c	Crop Evapotranspiration
ET_0	Reference Evapotranspiration
FAO	Food and Agricultural Organization of United Nations
FMIS	Farmer Managed Irrigation System
H_c	Height of Water level in canal at center along flow
H_l	Height of Water level in canal at left side along flow
H_r	Height of Water level in canal at right side along flow
H/H	House Hold
JICA	Japan International Cooperation Agency
K_c	Crop Coefficient
MAD	Management Allowed Depletion
MSIS	Medium Scale Irrigation Scheme
NRCS	Natural Resource Conservation Service
OARI	Oromia Agricultural Research Institute
OC	Percent of Organic Carbon
OM	Organic Matter
OWRB	Oromia Water Resource Bureau
RCBD	Randomized Completely Block Design
SMD	Soil Moisture Deficit

SWC	Soil and Water Conservation
RH	Relative Humidity
RR	Runoff Ratio
RWH	Rain Water Harvesting
RWS	Relative Water Supply
SSH	Sun Shine Hours
TWR	Tail Water Runoff
USDA	United State Department of Agriculture

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TECHNICAL PERFORMANCE EVALUATION AND REDESIGNING OF KETAR MEDIUM SCALE IRRIGATION SCHEME, SOUTHEAST OF OROMIA REGIONAL STATE, ETHIOPIA

ABSTRACT

Irrigated agriculture produces about 40% of all food and fiber on about 16% of all cropped land. Low level of performance can be identified at any level and stage of irrigation systems. Improving irrigation performance to increase productivity is one of the main visions formulated by national and international organizations involved in water development. 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. To test performance of the scheme irrigation performance indicators, namely, conveyance, application, storage efficiency, water application uniformity, depletion fraction, runoff ratio, deep percolation, irrigation water use efficiency and scheme sustainability were done. It has three stations; Ketar-1, 2 and 3 and designed for 860 l/s discharge to irrigate 400 ha of land, whereas current measured discharge was found as 800l/s and was irrigating about 541.40 ha. The reason of discharge reduction is flow fluctuation due to climatic change. Potato was the selected crop for the experiment. Soil of the study area was found clay loam, moderate acidic, non-saline soil and has 3.44OM 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. Redesign was done due to low conveyance efficiency and existence of runoff and deep percolation loss. Design of lined secondary canal with flow of $0.518\text{m}^3/\text{s}$ was made. New reservoir of capacity $26,891.2\text{m}^3$ was also designed due to silt accumulation for previous one. 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 are recommendable for sustained design discharge.

1. INTRODUCTION

The development of new irrigated farms and rehabilitation of old irrigation schemes through investment of high capital resources are being pursued these days to meet the ever increasing human needs for food, fiber and energy. This scenario calls for monitoring and evaluation of the level of performance of irrigation schemes from time to time, both technically and economically. The evaluation should be aimed at maintaining the increased productivity of the farms, and to prevent the adverse environmental impact that may arise from the poor operation of the irrigation schemes.

Irrigated agriculture consumes more than 70 percent of the water drawn from the rivers and the proportion can reach 80 percent (FAO, 2002). The ultimate purpose of irrigated agriculture is to apply an 'intended' volume of water to crops in order to avoid undesirable stress throughout the growing cycle. Irrigation water should be applied at the right time and in the right amount for consistently high yields. Excessive water application reduces yields by transporting nitrates below depths of root penetration, and by displacing soil air for too long, causing a lack of oxygen to the roots. Water shortage also reduces yields (Asawa, 2008). Irrigated agriculture produces about 40% of all food and fiber on about 16% of all cropped land (FAO, 2000). As such, irrigated agriculture is a productive user of resources; both in terms of yield per cropped area and in yield per volume of water consumed. The non-consumed fraction of the water causes a variety of undesirable effects ranging from water-logging and salinity within the irrigated area to downstream water pollution (Bos *et al.*, 2005).

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. At the level of water distribution, there are innumerable references in the form of inequity of water distribution leading to major disparities between head and tail areas, deficit water supplies and loss of production in some location, or excess water delivery. 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). There are many negative impacts caused by inefficient operation of irrigation systems. Improper irrigation practices lead to inefficient water distribution, non uniform crop growth, 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). Efficient farm irrigation practices achieved through improving the efficiencies lead to improvement in crop production and economic viability of irrigated farm.

Improving irrigation performance to increase productivity is one of the main visions formulated by national and international organizations involved in water development. Water productivity for food production was a major issue at the second Water Forum held in March 2000 organized by the World Water Council in Hague, where a frame work for achieving water security was formulated. The conference set a target to increase food productivity of water by 30 percent by the year 2015 (FAO, 2002). This goal calls for evaluation of irrigation schemes aimed at increasing farm performance. There is increasing pressure to improve the water use efficiency of irrigated agriculture in developing countries. Over irrigation and excessive drainage losses are wide spread. Significant water savings can be achieved with an integrated approach to irrigation and drainage management (Brown, 2003).

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. From the studies made by many researchers earlier, it can be estimated further that the worldwide irrigation efficiency was less than 40 percent. This has resulted in some negative environmental impacts. For instance, our irrigation has resulted in rising saline ground water table leading to soil salinization. Amibara Irrigation Project and some irrigated farms in the lower Awash valley are some examples where soil salinity has developed as a result of inefficient water management. Many schemes currently operate significantly under their design capacity. It was estimated that scheme performance is on average 30 percent below design, implying a loss of about 230 thousand hectares of irrigated land, leading to only 410,000ha performing to the expectations (Seleshi *et al.*, 2010).

To address the problem of irrigation system performance large numbers of researches have been conducted all over the world, though to a limited extent in Ethiopia. Irrigation system evaluation is characterized by complex number of factors that play significant role in determining the level of its performance. Poor distribution and management of irrigation

water is major factor contributing to this inefficient situation. Adequate monitoring and evaluation of performance is needed to improve water management practices in order to improve water management practices and achieve an increase in overall efficiency of the projects (Sarma and Rao, 1997). Evaluation of irrigation system is to know whether the system is operating below or above selected critical levels and to take management decisions for taking measures. In effect, the evaluation process examines the design criteria such as field layout irrigation flows, and scheduling, adapted at the farm development phase. The performance of irrigation operation has to be evaluated periodically, both at system and at farm levels using indicators that have been established. The results and recommendations of the evaluation exercises when implemented contribute towards maintaining the sustainability of the farms, for economic utilization of the limited water resource and generation of new data and information for the design and operation of new irrigation schemes.

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 study was aimed to contribute to the improvement of irrigation efficiency and crop productivity of the farm.

The specific objectives of the study were:

2. To evaluate the surface irrigation efficiency of the Ketar medium scale irrigation scheme,
3. To determine the level of water productivity of the farm on which performance evaluation would be conducted using Potato as a representative crop ,
4. To redesign Ketar medium scale irrigation system to make it more efficient

2. LITERATURE REVIEW

Irrigated agriculture has developed most extensively in the arid and semi-arid regions and areas having prolonged dry spells. A review of the development of irrigation in the world is fascinating. It reveals the ingenuity and foresightedness of the ancient civilization in harnessing the recourses of nature for the benefit of man. The principal irrigation practice of the ancient times was diverting the flow of the springs and streams with temporary barriers constructed across them and irrigating the adjoining fields (Michael, 2008).

2.1. Irrigation in Ethiopia

Ethiopia has an important opportunity in water-led development, but it needs to address critical challenges in the planning, design, delivery, and maintenance of its irrigation systems if it is to capture its full potential. This report shows how Ethiopia can chart a practical path of initiatives that will allow it to support the scale-up of its irrigated agricultural sector, the growth of its small holder farmers, and the transition of its pastoralist communities to food and water security (Seleshi *et al.*, 2010).

According to MoWR (2001), although Ethiopia's water resource is large with 12 major river/drainage basins, with 111 billion cubic meters of runoff, and eleven major lakes comprising a total area of 750,000 ha, very little of it has been utilized for agriculture, hydropower, industry, water supply and other purposes. Due to this so far only about 160,000 ha (about 4%) of the potential irrigable land i.e. about 3.64 million ha (Table 1) has been developed in the country (NataTadesse and Bheemalingeswara, 2010).

Table 1. Irrigation potential in the river basin

Basin	Catchment Area (km ²)	Irrigation potentials (ha) (Respective recent master plan studies)			
		Small scale	Medium scale	Large scale	Total
Abay	198,890.7	45,856	130,395	639,330	815,581
Tekeze	83,475.94	N/A	N/A	83,368	83,368
Baro-Akobo	76,203.12	N/A	N/A	1,019,523	1,019,523
Omo-Ghibe	79,000.00	N/A	10,028	57,900	67,928
Rift Valley	52,739.00	N/A	4,000	45,700	139,300
Awash	110,439.30	30,556	24,500	79,065	134,121
Genale-Dawa	172,133.00	1,805	28,415	1,044,500	1,074,720
Wabi-Shebele	202,219.50	10,755	55,950	171,200	237,905
Danakil	63,852.97	2,309	45,656	110,811	158,776
Ogaden	77,121.00	-	-	-	-
Ayisha	2,000.00	-	-	-	-
Total	1,118,074.53	91,281	298,944	3,251,379	3,641,604

Source: (Seleshi *et al.*, 2010)

2.2. Existing Irrigation Schemes with Database

Much of the world's land is not cultivated. Irrigated land covers 230Mha of our world (FAO, 2008). Ethiopia comprise 112 million hectares (Mha) of land. Cultivable land area estimates vary between 30 to 70 Mha. Currently, high estimates show that only 15 Mha of land is under cultivation. For the existing cultivated area, our estimate is that only about 4 to 5 percent is irrigated, with existing equipped irrigation schemes covering about 640,000 hectares (Table 1). However, the study estimates that total irrigable land potential in Ethiopia is 5.3 Mha assuming use of existing technologies, including 1.6 Mha through RWH and ground water. This means that there are potential opportunities to vastly increase the amount of irrigated land. This means that a significant portion of cultivated land in Ethiopia is currently not irrigated. Among Ethiopian river basins Ketar medium scale irrigation is located in Awash River basin. (Seleshi *et al.*, 2010).

2.3. Medium Scale Irrigation

According to Ethiopian classification, it is irrigation scheme which is community based or publicly sponsored, covering 200 to 3,000 hectares. Based on data from IWMI (2007) and grey documents from MoWR (2001) and MoARD (2010), our estimate of 640,000 hectares of irrigation nationwide includes 128,000ha from RWH, 383,000 ha from SSI and 129,000 ha MSI/LSI. Examples of MSIs include the Sille, Hare, Ziway and Ketar irrigation schemes. The M/LSI includes the Fentale and Tibila schemes (Seleshi *et al.*, 2010).

2.4. Surface Irrigation

Surface irrigation systems apply water to the land by an overland water flow regime. Surface irrigation is the application of water by gravity flow to the surface of the field. These systems are based on the principle of moving water over the surface of the land in order to wet it, either partially or completely. They can be subdivided into furrow, border strip and basin irrigation. Either the entire field is flooded (basin irrigation) or the water is fed into small channels (furrows) or strips of land(borders) (Brouwer *et al.*,2013). The scheme layout up to field level, such as canals and drains, can be similar for each system (Andreas and Karen, 2002).

According to FAO (1989), 95% of the irrigated area in the world is under surface irrigation. Some of the major advantages of surface irrigation systems over other systems are that they are easy to operate and maintain with skilled labor, they are not affected by windy conditions and, with the exception of furrow irrigation, they are good for the leaching of the salts from the root zone. Generally, they are associated with low energy costs. Such irrigation systems are best suited to soils with moderate to low infiltration capacities and land with relatively uniform terrain and slopes less than 2% (James, 2012). Surface irrigation systems do have also disadvantages. They are less efficient in water application than sprinkler or localized irrigation systems. The spatial and temporal variability of soil characteristics, such as infiltration rate and texture, make water management practices difficult to define and implement. It is also difficult to apply light, frequent irrigation required early and late in the cropping season. Another disadvantage can

be the high labour demand, as compared to sprinkler and localized irrigation systems, in situations where labour is not abundant (Andreas and Karen, 2002).

2.4.1. Basin irrigation

A basin is a horizontal area of land surrounded by earthen bunds and totally flooded during irrigation. Basin irrigation is the most common type of surface irrigation. It is particularly used in rice cultivation, where the fields are submerged, but it is equally suitable for other crops like cereals, fruit trees and pastures – as long as water logging conditions do not last for too long. Ideally, the water logging should not last longer than 24-48 hours. It is also used for the leaching of salts by deep percolation in the reclamation (FAO, 2002).

2.4.2. Border strip irrigation

Border strips, border checks or strip checks are strips of land separated by small earth bunds that guide the water as it flows down the field. They can have rectangular or contoured shapes, depending on the field. The border strip slopes uniformly away from the direction from the source of the irrigation water. They should be leveled across, in order to allow for the even wetting of the whole area, covered by a border and allow free drainage at the end. Normally, water is let onto the field from the canals through siphons. The siphoned water spreads across the width of the border when there is no cross slopes, thereby facilitating uniform water application. Uneven border slopes and cross border slopes are some of the most common problems that result in low irrigation efficiencies (FAO, 2002).

2.4.3. Furrow irrigation

Furrow irrigation is accomplished by running water in small channels (furrows or corrugates) down the slope of a field. Water infiltrates from the bottom and sides of the furrow moving laterally and downward to wet the soil. Soluble salts, fertilizers, and herbicides are moved with the water. Water is conveyed to the field along the head of the field in open ditches or in pipes. Various outlet devices are used to divert water into each furrow. Outlets of equal size with uniform pressure head are desirable to deliver nearly equal flows to all furrows irrigated in one set. The type of conveyance system and outlet

employed and degree of automation influence the capital cost of the system and the labor requirements process (Smathers and King, 2011).

A furrow irrigation system consists of furrows and ridges, of which the shape, spacing and length depend mainly on the crops to be grown and the types of soils. Siphons are mostly used to take water from the field ditch to the furrows. According to Kay (1986), the width of the furrows varies from 250-400 mm, the depth from 150-300 mm and the spacing between the furrows from 0.75-1.0 m, depending on soil type, crops and stream size to be applied to the furrow. Coarse soils require closely-spaced furrows in order to achieve lateral water flow in the root zone. There is more lateral water flow in clay than in sand. Typical furrow lengths vary from about 60 m on coarse textured soils to 500 m on fine textured soils, depending on the land slope, stream size and irrigation depth. The minimum and maximum slopes for furrows should be 0.05% and 2% respectively in areas of low rainfall intensity. In areas where there is a risk of erosion due to intensive rainfall, the maximum slope should be limited to 0.3%.

2.5. Crop Water Requirement

The net irrigation requirement (IR_n) does not include losses that are occurring in the process of applying the water. (IR_{n0}) plus losses constitute the Gross Irrigation Requirement (IR_g). The depth of irrigation application is the depth of water that can be stored within the root-zone between the field's capacity and allowable level of the soil water depleted for a given crop, soil and climate. It is equal to the readily available soil water over the irrigate zone (James, 1988).

The root zones of annual crops develop at about the same rate as top growth. Full root depth usually occurs before flowering or when full canopy cover is achieved. When planning early season irrigation, only consider the active root depth to calculate the maximum allowable soil moisture deficit (Werner, 1993).

2.6. Performance Evaluation of Irrigation Scheme

Performance is the level of achievement of desired objectives (Mohtadullah, 1993). Indicators are used to measure performance. An indicator is some number that describes the level of actual achievement in respect of one of the objectives of irrigation system. They

are used to simplify the otherwise complex internal and external factors affecting the performance of irrigated agricultural system. Performance can be measured from process and output points of view. Process measures of performance relate to a system's internal operations and procedures whereas output measures of performance examine the quality and quantity of the system's final output. While quoting the value of certain indicators, at a particular irrigation system and time, it means that all other factors and processes are ignored or neglected. The fact that an indicator services as a guideline for further decision making it should be carefully chosen, measured and interpreted. Irrigation performance, whether bad or good, is the result of verities of activities such as planning, design, construction (Seleshi *et al.*, 2007). Irrigation performance measures are based solely on the irrigation-water balance (Merriam *et al.*, 1999).

Lenton (1986) described irrigation performance as knowing the extent to which an irrigation scheme achieved established objectives. According to Abernethy (1989) the performance of an irrigation scheme is represented by "its measured levels of achievement in terms of one, or several, parameters which are chosen as indicators of the system's goals." While reviewing and proposing different methodologies for assessing performance of irrigation and drainage schemes, Bos *et al* (1994) commented, "performance assessment is, despite its apparent simplicity, a very complex task" and cited the definition of performance proposed by Murray-Rust and Snellen (1993) as "the degree to which an organization's products and services respond to the needs of their customers or users, and the efficiency with which the organization uses the resources at its disposal". The performance of irrigation water management can be stated as "the extent to which the land and water resources in the irrigation schemes planned for allocation to different users and their spatial and temporal distribution in planning and operation stages follow the objectives of the irrigation scheme" (Repository, 2005).

The principal objective of evaluating surface irrigation systems is to identify management practices and systems that can be effectively implemented to improve the irrigation efficiency. (Brouwer *et al.*, 2013) has cited that evaluations are useful in a number of analyses and operations, particularly those that are essential to improve management and control. Evaluation data can be collected periodically from the system to refine management practices and identify the changes in the field that occur over the irrigation

season or from year to year (FAO, 1989). As many FMIS (farmer managed irrigation systems) do not perform as well as they should, there is a need to identify the areas in which they fall short of their potential. It is therefore important to measure and evaluate their success or failure objectively and identifies specific areas in need of improvement (Jorge, 1993). The evaluation of surface irrigation at field level is an important aspect of both management and design of the system.

There were research works done for evaluating the efficiency of the schemes in Ethiopia. According to the study of Yusuf, 2004 on Doni and Batu irrigation scheme, Doni irrigation has been performing better than Batu. Assessment of Gerado small-scale irrigation scheme, Dessie zuria woreda, indicated that there were shortages of water supply during growing periods. Conveyance losses on primary canals were significant and poor conveyance system management and irrigation scheduling and poor methods of irrigation practice (uncontrolled flooding) are main problems identified in the management and operations (Solomon, 2006).

2.7. Irrigation Efficiencies

Irrigation system performance describes the effectiveness of the physical system and operating decision to deliver water from a water source to the crop. Several efficiency terms are used to evaluate irrigation system performance. These include water conveyance efficiency, overall irrigation efficiency, soil water storage efficiency, and the likes.

2.7.1. Conveyance efficiency

Irrigation water is normally conveyed from water source to the farm through natural drainage ways, constructed earthen canals, or pipe. Many conveyance systems have transmission losses, meaning that water delivered to the farm or field is usually less than the water from the source. Conveyance losses include any canal spills (operational or accidental) and reservoir seepage and evaporation that might result from management as well as losses resulting from the physical configuration or condition of the irrigation system. The conveyance efficiency is typically defined as the ratio between the water that reaches a farm or field and that diverted from the irrigation water source (Howell, 2003).

According to Rao (1993), conveyance is the movement of water from its source through the main and lateral or secondary canals or conduits to the tertiary off take. The

conveyance efficiency, E_c is the efficiency of canal and conduits network from the reservoir, river diversion, or pumping station to the off take of the distributor system.

2.7.2. Application efficiency

The irrigation capacity is the rate the water can be delivered to the field. Irrigation application capacity defines the ability of the irrigation system to meet crop water use and refill the soil profile. Water application efficiency (E_a) provides general indication of how well an irrigation system performs its primary task of delivering water from conveyance system to crop. The objective is to apply the water and store in the crop root zone to meet the crop requirement. E_a is a measure of the fraction of water stored in the root zone to meet the crop evapo-transpiration (ET) needs to the total volume of water delivered to the farm or field (Werner, 1993).

Field application is the movement of water from the field to the crop. Application efficiency, E_a is the relationship between the quantity of water furnished at the field inlet and the quantity of water needed to maintain soil moisture at the level required by the crop. This is an indirect way of establishing the field application efficiency, since the water used by evapotranspiration of a crop equals the amount of water needed to maintain the required soil moisture for the crop (Rao, 1993). Application efficiency is the most important parameter in terms of design and management since it reflects the overall beneficial use of irrigation water (Walker, 1989) cited by (Singh and Sharma, n.d).

2.7.3. Application uniformity efficiency

Uniformity of application describes how evenly an application system distributes water over a field. It is measured by Christiansen coefficient (C_u). All irrigation systems apply water non uniformly to a varying degree. Irrigation system performance efficiency described previously do not directly account for the uniformity or non uniformity of irrigation application within a given field. Yet, the non uniformity of the applied water can significantly affect irrigation performance. Non uniform irrigation application results in areas that are under-watered or over-watered. Crops may experience water stress in areas that are waterlogged for several days. Over watering may cause surface runoff and/ or leaching of nutrients below the root zone. Thus, both under-watering and over-watering may experience yield reduction. With favorable conditions, optimum crop growth and

yield are obtained with high uniformity of irrigation application in which each plant has an equal opportunity to access the applied water and nutrients (James, 2012).

The uniformity irrigation application depends on many factors that are related to method of irrigation, topography, soil (infiltration) characteristics, and the irrigation systems pressure and flow rate. For surface irrigation, non uniformity can be caused by: differences in opportunity of time for infiltration caused by advance and recession, spatial variability of soil infiltration properties, and non uniform grades. Distribution Uniformity is usually defined as the ratio of some measure of the smallest accumulated depths in the distribution, to the average depth accumulated. In principle a uniformity ratio could be defined equally well in terms of a measure of the largest values in the distribution (Burt, 1989).

2.7.4. Water storage efficiency

The main goal of most irrigation application is to maximize water in the soil root zone to satisfy crop ET while minimizing deep percolation and surface runoff. The soil water storage efficiency indicates how well the system uses the available root zone storage capacity to store water to meet crop needs. Thus, in most cases, minimizing water storage from irrigation is beneficial. The storage efficiency is an indicator of how well the irrigation meets its objective of refilling the root zone. The value of the storage efficiency is important when either the irrigation tends to leave major portions of the field under-irrigated or where under irrigation is purposely practiced to use the precipitation as and when it occurs (Singh and Sharma, n.d).

Water stored in the root zone is not 100% effective. Evaporation losses may remain high due to the movement of soil water by capillary action towards the soil surface. Water lost from the root zone by deep percolation where groundwater is deep. Deep percolation can persist after attaining field capacity. Depending on the weather, type of soil and time span considered, effectiveness of stored soil water might be as high as 90% or as low as 40% (FAO, 1992).

2.8. Surface Irrigation Water Losses

All water taken from a source (river, well) does not reach the root zone of the plants. Part of the water is lost during transport through the canals and in the fields. The remaining part is stored in the root zone and eventually used by the plants. In other words, only part of the

water is used efficiently, the rest of the water is lost for the crops on the fields that are to be irrigated. Irrigation water losses in canals are due to evaporation from the water surface, deep percolation to soil layers underneath the canals, seepage through the bunds of the canals, overtopping the bunds, bund breaks, runoff in the drain, and rat holes in the canal bunds (FAO, 1989).

Water management and determination of consumptive water use in irrigated agricultural settings depend on understanding factors such as surface-water diversions, groundwater withdrawals, evapotranspiration, tail-water runoff, and deep-percolation return flow of water beneath irrigated fields (Arnold, 2011). Water losses during surface (furrow) irrigation include runoff, evaporation from water in furrow channels, evaporation from the soil surface, and percolation below the root zone. Runoff losses can be significant if tail-water is not controlled and reused. In cases where runoff water is recovered and reused, the volume of irrigation water recovered and reused, the volume of irrigation water delivered to farm or field (V_f) should be adjusted to account for the net recovered tail water (Irmak *et al.*, 2011).

Runoff is surface water that leaves the subject region in liquid form. Clearly, what constitutes runoff in a given region can be destined for infiltration and/or transpiration in a downstream region. Surface water captured and reapplied within the subject region is not classified as runoff from the subject area. It may be useful to note its temporary status, in connection with energy use for pumping or degradation in quality, but it does not enter into the water balance or considerations of efficiency if it is captured and reapplied within the boundaries (translocation) (Burt *et al.*, 1978).

Deep percolation is infiltrated water which moves below the root zone. For a crop with active roots throughout a root zone, almost all of the deep percolation will occur within a short time of the completion of irrigation. For water stored in a potential root zone (with no active roots), the concept of field capacity is more dynamic, and slow drainage (deep percolation) will occur for several months in a heavy, high clay content soil (Jensen, 1990) as cited by Clemmens and Burt, 1997.

2.9. Improving the Performance of Furrow Irrigation

Uniform application of water using furrow irrigation is difficult to achieve. As water advances down a field, the opportunity time, or the time water has to infiltrate the soil, is greater at the upper end of the field than the lower. For example, if water advance in the furrows takes six hours to reach the end of a field, and total set time is 12 hours, then the opportunity time is twice as long at the head of the field. Non-uniform furrow irrigation, a primary cause of deep percolation, is usually more pronounced during the first irrigation of the season. Early in the season, soil is loose because the soil has not yet consolidated due to irrigation or rainfall. Cultivation and furrow construction loosen the soil further and encourage surface soil water evaporation. In addition, root activity early in the growing season depletes soil water in the top layers of the soil. All of these conditions can result in dry, loose soil making irrigation difficult. If moving water down the field is difficult, non uniform irrigation will result, causing deep percolation of water below the root zone, particularly at the head end of the field(Yonts and Engineer, 2007).

When faced with difficult furrow irrigation conditions, several alternatives are available. Furrow stream size can be increased to improve irrigation uniformity by reducing advance time and allowing a more equal amount of water to be applied at the top and bottom of a field. Increased runoff and the potential for soil erosion is the disadvantage of large stream size. Another alternative is to extend the irrigation set time to allow water movement down the furrow to the end of the field. However, when set times are increased beyond 12 hours, the opportunity for water to infiltrate at the top of the field increases and deep percolation can result. Any process allowing water to advance in a furrow and reach the end of the field faster will help improve water distribution and obtain more uniform irrigation. For proper design of the furrow length, factors which have to be taken into account are soil type, stream size, irrigation depth, slope, field size and shape, cultivation practices. Furrows should have a uniform longitudinal slope between 0.05 and 2 percent for drainage and minimizing soil erosion respectively. Sandier soils have almost vertical wetting pattern while clay soils have both vertical and lateral wetting patterns. Hence, sandier soils should have closer furrow spacing than clay soils. Furrow spacing also depends on type of crops to be planted. In general, furrow spacing varies from 0.3 to 1.8

with the commonly used spacing being 0.5 m on sandy soils and 1.2 m on clay soils (FAO, 2002).

2.10. Water Productivity and Water Delivery Performance Indicators

Irrigation productivity is a measure of the economic or biophysical gain from the use of a unit of irrigation water in crop production and is expressed in productive crop units of kg/ha-cm, kg/m³ or \$/m³. As the name portrays, this is the product that is obtained from the irrigated crop to which the diverted water was planned for. The main difference between efficiency and productivity is that efficiency refers only to physical quantities of water, both in the denominator and the numerator. It does not capture differences in the value of water in alternative uses. Gains in basin efficiency can make an important contribution to gain in productivity (Bruce *et al.*, 2004).

The water utilization by crop is generally described in terms of water use efficiency (kg/ha-cm, kg/m³ or q/ha-cm) (Michael, 2008). Water use efficiency (WUE) and irrigation water use efficiency (IWUE) were determined by dividing the yield to seasonal ET and total seasonal irrigation water (IW) applied (Sinclair *et al.*, 1984). Application of the yield response factor for planning, design and operation purposes allows the quantification of water supply and water use in terms of crop, yield and total production for the scheme (Doorenbos and Kassam, 1986).

2.11. Scheme Characterization

When the water available from a particular source is limited then it has to be used very carefully, it is useful, and even necessary, to measure the discharge at various points in the system and the flow at farmers' intakes. Flow measurements may also be useful for settling any disputes about the distribution of the water. In addition, measurement of the flows can provide important information about the functioning of the irrigation system (FAO, 1993).

2.12. Design Parameters for Surface Irrigation Structures

Design of a surface irrigation system may be required for either a planned new irrigation scheme or an existing irrigation scheme where low performance requires improvement by redesigning the system. In both cases, the data required fall into six categories: the water resources to be used, including source of water, flow rates and water quality, the

topography of the land surface, the physical and chemical characteristics of the soil, including infiltration rates, soil moisture holding capacities, salinity, the expected cropping pattern, the economic and marketing situation in the area and the availability of services, including the availability of labour, maintenance and replacement services, energy, availability of capital for the work, farming practices of the overall farming enterprise (Andreas and Karen, 2002).

Many irrigation schemes around the world do not provide adequate service to farmers, because gates can no longer operate due to rust or because parts are missing or broken, canal sections have collapsed or are full of silt, water level gauges have disappeared, etc. All of the above are the result of poor maintenance (FAO, 1996).

One of the most important problems for an on-demand irrigation system designer is the calculation of the discharges flowing into the network. Such discharges strongly vary over time depending on the cropping pattern; meteorological conditions, on-farm irrigation efficiency and farmers' behavior. Two individual factors, the available water supply and water demand are basic factors in irrigation planning, design and operation. Combined, they provide a variable with utility for both practical and theoretical applications. This variable, the RWS, can be defined as the ratio of supply to demand (Rao, 1993).

The amount of water to be supplied during an irrigation event, referred to as the target or required depth of application, d_{req} , is a major design consideration. Surface irrigation systems have a narrow range of target depths for which they are reasonably efficient and uniform. Design approaches are often based on assuming that one end of the field or the other will receive the least infiltrated depth. Then, the inflow and application time are adjusted such that the required depth is infiltrated at that location. The time to infiltrate the required depth becomes an important design parameter (Clemmens, 2007).

Good design incorporated with good management of irrigation systems is critical to achieving high irrigation efficiency. Without good design, irrigation efficiency improvements that can be made with management are limited and are in fact hampered (Bright *et al.*, 2000) cited by (Rose, 2006). Lining of canals is an important feature of irrigation projects as it improves the flow characteristics and minimizes the loss of water due to seepage (Kisan *et al.*, 2000).

3. MATERIALS AND METHODS

3.1. 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. The woreda is bordered on the south by Munesa, on the west by Ziway Dugda, on the northeast by Hitosa, and on the southeast by DigelunaTiyo. The administrative center of the woreda and Zone is Asella; other towns in Tiyo include Gonde. A survey of the land in this woreda shows that 40% is arable or cultivable (32% was planted with cereals), 23.1% pasture, 8.7% forest, and the remaining 28.2% is considered swampy, mountainous or otherwise unusable.

Ketar irrigation scheme uses diverted water from Ketar River. Diversion of the scheme starts from the river which crosses the road taking from Asella to Munesa woreda. The river arises from the glaciated slopes of Mount Kaka and Mount Badda in the Arsi Zone. The gradient of the river is generally steep, and areas suitable for irrigation are few in number and very limited in extent with a watershed of 3,400 km². It drains into Lake Ziway (Yazachew and Kasahun, 2011).

The climate here is mild, and generally warm and temperate. The rainfall in Tiyo is significant, with precipitation even during the driest month. According to Kottek *et al.*, (2006) this climate is classified as Cfb which means mild with no dry season. The Cfb climate is temperate oceanic climate; coldest month averaging above 0 °C (32 °F), all months with average temperatures below 22 °C (71.6 °F), and at least four months averaging above 10 °C (50 °F). No significant precipitation difference between seasons (neither abovementioned set of conditions fulfilled).

The average annual temperature is 13.8°C. At an average 15.1 °C, April is the hottest month of the year. At an average 12.7 °C December is the coldest month of the year. The average annual rainfall of the woreda is 1118 mm. Precipitation is the lowest in December, with an average of 12 mm. In July, the precipitation reaches its peak, with an average of 187 mm. The woreda has an altitude of 2430m above sea level (asl) (Yazachew and Kasahun, 2011).

The study area has normal weather conditions. If *Belg* rain is late and extended dry period during that short rainy season have had a negative impact on Belg crops, Meher long rains conditions have been good. All over the zone, rains are expected up to first decade of October to assure very good crop maturation. Some parts of the lowlands have reported delaying of onset of rain, but conditions appear as good except excess of rain and hail storms having affected some crops mostly in the highlands.

Ketar medium scale irrigation scheme is located at about 25 km from Asella in Kebele so called Golja and is diverted from Ketar river. It has three stations; Ketar-1, Ketar-2 and Ketar-3, and was designed to irrigate around 400 ha of land. Crops which are dominantly grown are onion and potato.

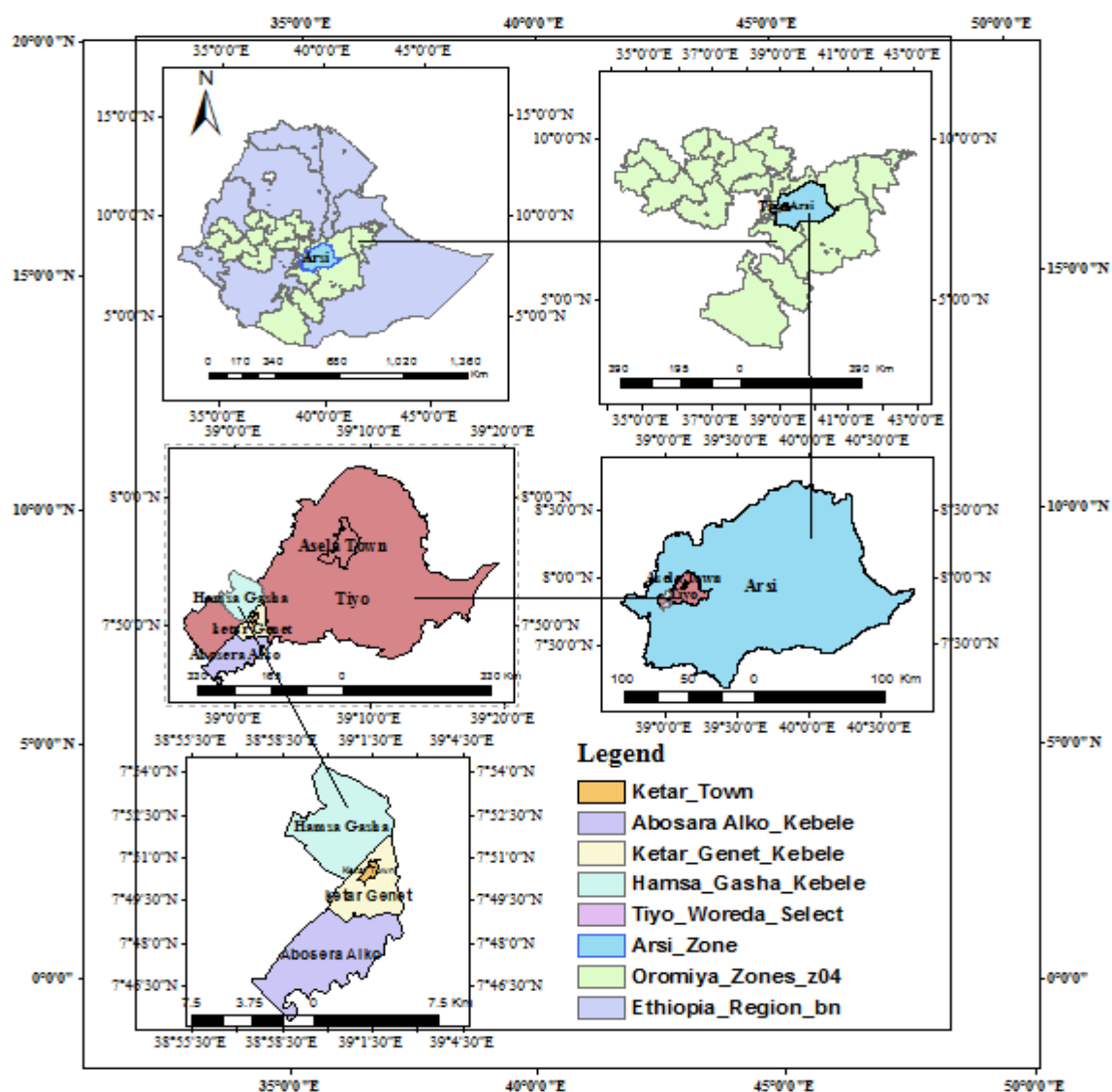


Figure 1. Location Map of Study Area

3.2. Data Collection

Data collection plays a vital role in testing irrigation scheme and then for analyzing. Data collected for this study area was primary and secondary. Primary data were soil sample collection for bulk density, organic matter content, soil texture and pH determination, discharge measurement by current meter and structures at diversion head work, main canal, secondary canal of the three schemes and discharge measurement at field level by using Parshall flume.

3.2.1. Primary data collection

To check the technological gap in the study, the condition of infrastructure and the discharge rate at main, secondary and tertiary canals were measured. Three inch (3'') Parshall flume was used to measure discharge through field channel. Points at measurement taken had regular and irregular shapes. For calculating area for regular canal shapes like trapezoidal and rectangular their respective formula were used. In the case of irregular shapes or earthen canals they were divided into partitions of small trapezoidal shapes across the canal and the total area were computed by their summation of each partition. Discharges were measured at necessary points. Measurements taken were at diversion weir and at primary, secondary, tertiary and field channel at head, middle and tail locations of the scheme.

Moisture contents of the soil before and after irrigation were estimated and soil samples for laboratory analysis were collected from two soil depths (0-30 cm and 30-60 cm) of the field. To determine the soil texture, organic matter content, pH and EC, disturbed soil samples and for bulk density, moisture content at field capacity and permanent wilting point undisturbed soil samples were collected by core sampler and were taken to laboratory for analysis.

For primary data collection, proper sites were selected for taking different observations. Site selection was based on the large number of users of the scheme. For this site inspection was done along the flow direction of the irrigation system. According to the inspection large numbers of users were located at the right direction of the scheme which could represent the left side as well. Total of nine potato grower farmers' plots, three from each station were selected.

To identify difference between actual achievements and the management target, information was gathered related to the size of the irrigation area served by irrigation scheme in a given season, cropping intensity, irrigation efficiencies, and water delivery schedules in actual field conditions and theoretically same were estimated by using CROPWAT-8 software.

3.2.2. Secondary data collection

Secondary data collected includes data which describe the original scheme and design command area and scheme management. The data collected from the secondary source include procurement of necessary documents and other useful written and published materials related to the scheme.

Information related to total irrigated area covered by the scheme, area irrigated per crop per season/year, crop types, cropping pattern, market price of crop (local), were gathered , information such as agricultural and economic profitability of irrigated agriculture, productivity per unit of irrigation water and environmental problems such as water logging and salinity were also gathered. The meteorological data were collected from Chebi Meteorological Station and National Meteorology Agency and was used for crop water requirement. Data which concerns about design and management of the scheme were collected from TiyoWereda Irrigation Authority and Oromia Irrigation Development Authority.

3.3. Scheme Characterization

Scheme characterization included description of the structures starting from diversion head work through irrigation regulators up to command area based on the type of irrigation method being used at project area. To carry out this, visits and observations of the scheme were done and functionality of the structures was assessed. Then it was compared with the design document which had been prepared for scheme.

3.4. Field Layout

This study considered representative parameters of the scheme. The farmers were selected for observations both along and across the slope of the command area. From each location along the slope (up, middle, and down), three farmer's plot from left, centre, and right

across the slopes of the command area were selected with a total of nine farmer's fields and the field assessment was undertaken. The assumption behind the selection criteria of the farmer's fields were that first to increase the sample size and to check if there would a tendency of the upstream users to over irrigate their crops while the tail users facing in short supply of irrigation water (FAO, 1998; Levin *et al.*, 1998 and Bos *et al.*, 2005).

Potato crop was selected for the experiment as it has been commonly grown in all the nine selected farmer field. This helped to compare the water productivity and economic return per unit of water use. Experimental design was based on completely randomized block design type. For plot size selection, the length of plot was based on farmer's farm width whereas its length was 25m for each plot.

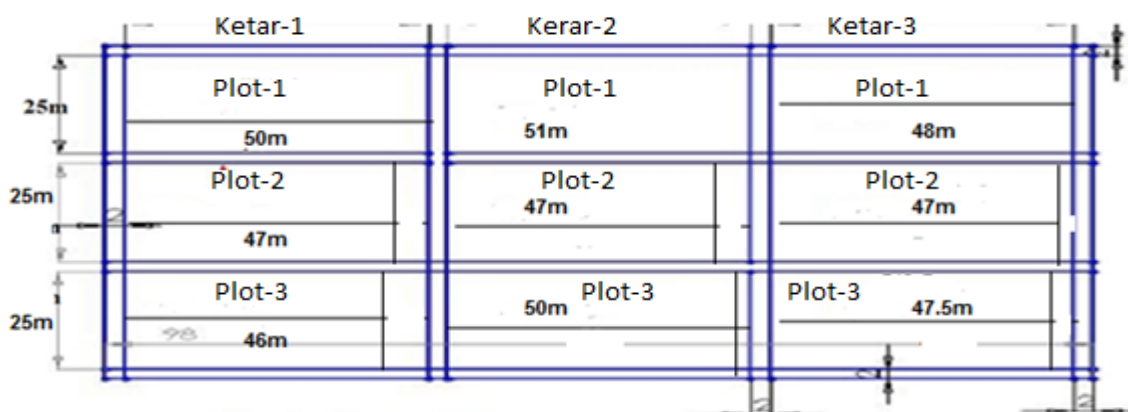


Figure 2. Experimental Field layout

3.5. Soil Sampling

Soils of the experimental site were characterized in terms of physical and chemical properties. The physical and chemical properties of the soil in the study area (organic matter content, texture, bulk density, moisture content at field capacity, permanent wilting point, and infiltration capacity) was measured to characterize soils of the study site. Soil samples were collected for the laboratory analysis of soil textures, organic matter contents, Soil pH, and electrical conductivity. Textural analysis was done by Hydrometer method and grouped by USDA textural triangle.

Using soil core sampler, undisturbed soil samples were collected and taken to oven dried for bulk densities determination, whereas for field capacity (FC), and permanent wilting

point(PWP) determination, disturbed soil sample was collected from two depths(0-30 cm- and 30-60cm) and dried, grinded, saturated and taken to pressure plate apparatus and membrane apparatus at 0.33 bars and 15 bars pressures respectively. The double ring infiltrometer of 60cm diameter for outer ring and 30cm diameter for the inner one was used to measure infiltration characteristics of the soil.

For textural analysis of the soil, disturbed composite soil samples were collected from two depths 0-30cm and 30-60cm at three points diagonally of the experimental site. Hydrometer method was used for analyzing particle size distribution and USDA textural triangle (USDA, 1972) was used to identify the textural class

The organic matter content of the soil was determined by titration method. The soil was oxidized under standardized condition with potassium dichromate in sulphuric acid to determine the carbon content. The status of organic matter content was obtained by multiplying carbon content with 1.724 (Walkley and Blank, 1934 cited by Schutter *et al.*, 2008).

The soil bulk density was determined from undisturbed soil samples collecting by core samplers at two depths of 0-30 cm and 30-60cm, and was analyzed after oven drying the samples for 24 hours at 105°C and weighed for calculating dry density using equation (3.1) given by Hillel (2004):

$$\rho_b = \frac{M_s}{V_t} \quad (3.1)$$

where, ρ_b = soil bulk density (gm/cm³)

M_s = mass of dry soil (gm) and

V_t = total volume of soil in the core sampler (cm³)

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.

3.6. Crop Water Requirement and Irrigation Water Requirement

Planting dates for potato in the selected nine fields were obtained from the usual practice of the farmers. CROPWAT version-8 was used and climatic data were fed to calculate the

reference evapotranspiration (ET_o) of the study area. In addition, mean monthly rainfall data was collected from Asella (Chebi) Meteorological Station and National Meteorological Agency. The monthly net crop water requirement (CWR) and the net irrigation water requirement (IWR) of the crop were computed by using equation (3.2) for each irrigation event.

To compute ET_o , input information average maximum and minimum temperatures, relative humidity, wind speed and sun shine hour of each month for ten years were used to run the CROPWAT version 8 software. Data of relative humidity had four readings for each day, therefore, its average was computed as reading was taken for times (6:00, 9:00, 12:00, 15:00, 18:00) and this average was used as input in the software. Crop coefficient (K_c) values of the selected crop (potato) for each growth stage i.e initial, developmental, mid and late growth stage were found 0.45, 0.75, 1.13 and 0.90 respectively. Length of crop development stages for Potato is 115-130 days which is 25, 30, 30/45 and 30 for initial (from planting date to approximately 10% ground cover.), developmental(10% ground cover to effective full cover), mid(from effective full cover to the start of maturity) and late (from the start of maturity to harvest or full senescence)growing stages respectively for semi and arid climates (Andreas and Karen, 2002). From ET_o which has been determined at each growth stages ET_c was computed as:

$$ET_c = ET_o \times K_c \quad (3.2)$$

where, ET_c = crop evapotranspiration (mm/day)

ET_o = reference crop evapotranspiration (mm/day)

K_c = crop coefficient

Gross irrigation water requirement for the crop was calculated using net-irrigation requirement of the crop, irrigated areas and irrigation efficiency in depth basis (equation 3.4) whereas irrigation interval was calculated using equation 3.3

Irrigation interval was calculated as;

$$I = \frac{d_{net}}{ET_c} \quad (3.3)$$

$$d_{gross} = \frac{d_{net}}{E_a} * 100 \quad (3.4)$$

where, I = irrigation interval (days)

d_{net} =net-depth of irrigation(mm)

d_{gross} =gross irrigation depth(mm)

E_a =Application Efficiency (%)

ET_c =daily crop evapotranspiration (mm/day)

The moisture deficit (d) in the effective root-zone was found out by determining moisture contents at the field capacity and bulk densities of each layers of the soil (Mishra and Ahmed, 1990).

$$d = \sum_{i=1}^n \frac{(FC_i - PWP_i)}{100} * \gamma_i * D_i * P \quad (3.5)$$

where,

FC_i = field capacity of the irrigation water layer on oven dry weight basis (%)

PWP_i =actual moisture content of the irrigation water layer on oven dry weight basis (%)

γ_i =apparent specific gravity of the soil of irrigation layer

D_i =depth of the irrigation layer (mm)

P= depletion fraction (%)

n= number of layers in the root zone

According to Jurriens *et al.*,(2001), the required depth (d) is not usually the same as that applied depth (d_a) which is equal to the applied volume (m^3) divided by the area (m^2). If the applied depth infiltrates the field area entirely, the applied depth equals the average infiltrated depth (D_{ave}). Jurriens *et al.*, (2001) further discussed on that, the average depth of water that is actually stored in the target root zone D_{req} is the storage depth (D_s). When the target zone is entirely filled, D_s will equal D_{req} . If $D_s < D_{req}$, then there is under-irrigation and if $D_s > D_{req}$, then there is deep-percolation.

3.7. Measurement of Soil and Water Utilization in the Field

Real performance is based on water uses over the specified period of time, rather than observation of a single irrigation event (Clemmens and Burt, 1997). Taking this into account, the field assessment on water utilization efficiency and so the performance of the selected farmer's field with schemes was done on three irrigation events.

Measuring water use and soil moisture is crucial for calculating irrigation efficiency (Edkin, 2006). Therefore, during each irrigation event, water flow into the fields, moisture contents of the soil profile (before and after two days of irrigation) and by using water can, the runoff volume at the end of each field was measured carefully.

3.7.1. Inflow and outflow water measurements at field

Discharge measurements at selected points were done by current meter and Parshall flume. Current meter was used for discharge measurement at diversion head, main canal, secondary canal and tertiary canals of station. As stated by (Buchanan and Somers, 1969) for water depths lower than 1m were multiplied by 0.6H (one point method), where as when depth was greater than 1m, the current meter was placed at 0.2H and 0.8H (two point method) for water velocity measurement. At canal section where flow was no free flow structures were used as measuring discharge and processed their respective formulae (rectangular : $Q = \frac{2}{3} C_d \sqrt{2g} L H^{3/2}$ and Trapezoidal $Q = 1.86 b H^{3/2}$ where discharge coefficient C_d ranges 0.60-0.69.

Discharge at Ketar-2 main and secondary canals were measured by structure as flow speed at not free flow to measure by current meter. Therefore measurement was done using structures and processed to their respective empirical formula for discharge estimation based on their shape.

Parshall flume was designed and constructed at Asella Agricultural Engineering Research Center based on its standard dimension. Before releasing water to flow through the flume its sitting was corrected by water level both along and across water flow. Then flow of water into field was measured using 3" (3 inch) size Parshall flume at the entrance of the water flow to the field.

$$Q = C_f (KH)^{n_f} \quad (3.6)$$

For 3'' Parshall flume, $Q = 0.1771H^{1.550}$ (3.7)

$$V_a = Q * \Delta t \quad (3.8)$$

where; Q= discharge through the flume (l/s)

C_f = discharge coefficient from rated tables

K = unit constant (K= 3.28 for H in m)

n_f =flow exponent from the tables

V_a = total volume of water applied (m^3)

Δt =flow time to the field (seconds)

The same discharge and the same irrigation time as the irrigators normally use was followed and irrigation will be allowed to continue until the farmers perceive that enough amount of water is applied to the fields.

To collect the out flowing tail water, a pit and runoff diversion channel was excavated and known volume of runoff collection bucket was put inside the pit. To prevent seepage of the tail water into the runoff diversion channel, plastic sheet of the same length as the channel was laid. Parshall flume was installed at the entrance of runoff water to the pit and measurement was taken until flow stopped.

Efficient management of an irrigation system insists that measurement of the rate-of-flow and volume delivered be made. Discharge measurement had been done at points of required places. It had been taken at diversion weir, main canal, secondary canal and field channel of the three stations. Current meter had been used for flow velocity measurement from diversion weir to secondary canal. The speed of the meter, after it was inserted at a point where velocity is to be measured, was obtained by starting a stop watch on a click and stopping it on another click after 45 seconds. The reading had real and average velocity reading simultaneously and was converted to discharge by mean section method. For measuring discharge of selected points of water depth in the canal had been measured at left, center and right of places across the flow.

Flow velocity had been measured at 20%, 60% and 80% of flow depth but only measurement at 60% was taken since all of the water depth was less than 1m. To determine discharge at selected points, measurement of wetted cross sectional area and velocity had been done. To measure cross sectional area; formula had been used for regular shape structures. For irregular shape structures partition had been made into different trapezoidal shapes and their sum had been taken ($A = \sum_{n=1}^{n=1} A_n$). Then discharge had been determined by the product of respective area and velocity for each.

Before taking velocity measurement calibration was done for the manufactured Parshall flume based on the standard one. Their relationship was developed with discharge coefficient of 1.00189 which implies that the designed and manufactured Parshall flume was almost the same with the standard one. Discharge measurement was done at each crop growth stages and average irrigation period was determined for each plot as result mentioned in Table 9. Then the flow depth observed on the flume had been converted to the corresponding discharge using equation (3.6) or using simplified form of equation (3.7) for 3 inch size Parshall flume. Then the total volume of water applied (V_a) had been calculated using equation (3.8) (James, 1988) and the total depth of applied water was calculated based on the representative irrigated area.

3.7.2. Soil parameters measurements

To monitor the replenishment of soil moisture in the plant root zone, moisture status of the soil was measured periodically. The moisture status was measured to determine how much water was depleted below the field capacity before irrigation and how much water to apply to the root zone after irrigation. For these purposes, the soil water parameters such as soil moisture content were estimated periodically; whereas bulk density, field capacity, and permanent wilting point were determined once.

To do this, just before irrigation and two days after irrigation soil samples from each field to the depth of effective root penetration (i.e. 0-30cm and 30-60cm) were collected using soil auger and was taken to an oven dry for gravimetric moisture determination.

To collect representative soil samples from each field were collected from three rows (one at centre, and two from either sides) of the field and at three points of each row with two depths before and after three irrigation events (one in each growth stage).

Therefore, 108 samples from each farmer plot with a total of 972 soil samples were collected to measure the soil moisture status of the fields at different irrigation event for the nine farmers' fields.

3.7.3. Gravimetric sampling

Though numerous techniques were developed for evaluating soil moisture content, θ , in the soil profile, the standard method known as the gravimetric sampling method was used (Walker, 2003).

The moisture status of the soil profile for each field was measured before and after each irrigation event. Soil samples were placed in the air tight container and weighed by electronic balance prior to placing in an oven dry at 105 °C for 24 hour. The samples were left in the oven for 24hrs, although a constant dry weight (less than 0.1% change during an hour) was usually achieved prior to this (Walker, 2003). The oven dried soil samples with container and cover were weighed again and recorded. Core sampler which has 5cm diameter and 5cm height, whose volumes becomes 98.13 cm³ was used. After the soil moisture sampler collected and oven dried, the moisture has been calculated as a percentage of dry weight of the soil sample (W) using the following formula.

$$\mathcal{G}_m = \frac{M_t - M_s}{M_s} * 100 = \frac{M_w}{M_s} * 100 \quad (3.9)$$

where, $\mathcal{G}_m$ =soil moisture status in weight basis (%)

M_t =weight of fresh sample (gm)

M_s =weight of over dried sample (gm)

M_w =weight of soil moisture (gm)

Volumetric moisture content (θ_v) has been calculated using equation 3.10 as shown in appendix table 4.

$$\theta_v = g_m * \frac{\rho_b}{\rho_w} \quad (3.10)$$

where , θ_v =volumetric moisture content (%)

ρ_b = soil bulk density (gm/cm³)

W= moisture content on dry weight basis (%)

ρ_w = unit weight of water (gm/cm³)

3.8. Total Available Water (TAW)

The required amount of water for each irrigation event was measured using the water balance approach. The required amount of water is equal to the difference between the field capacity and the soil moisture prior to irrigation. FC and PWP were determined by pressure plate apparatus. Once FC and PWP determined TAW was calculated as the following formula.

$$TAW = \frac{(FC - PWP)}{100} * BD * D \quad (3.11)$$

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/cm³)

Total available water of each plots from field capacity and permanent wilting point at soil depth of 300, 450 and 600mm were achieved by multiplying with their respective bulk density and their average had been taken. For determination of soil field capacity and permanent wilting point nine samples from each station and totally 27 samples were collected and taken to Pressure plate Apparatus.

3.9. Determination of Irrigation System Performance Indicators

3.9.1. Irrigation efficiencies

Measurements were taken on the field and design figures were reviewed from secondary sources including the design document. Discharge was measured by using current meter and structures at the diversion weir, main, secondary and tertiary canals of the selected farmers from the three stations (Ketar-1, Ketar-2, Ketar-3). At point where water is conveyed to the command area (selected field) three inch Parshall flume was used. The technical evaluations were made for the following performance indicators; namely, technical efficiency including conveyance efficiency, application efficiency and water delivery performance; and maintenance indicators such as relative change of water level, effectively of infrastructure, dependability of duration and sustainability.

3.9.1.1. Conveyance efficiency

It is expressed as:

$$E_c = \frac{V_f}{V_t} * 100 \quad (3.12)$$

where, E_c = Water Conveyance Efficiency (%)

V_f = Volume of irrigation water that reaches the farm or field (m^3/s or ha-m)

V_t = Volume of irrigation water diverted from water source (m^3/s or ha-m)

Volume of irrigation water that reaches the farm or field was measured by Parshall flume for the nine plots and volume of irrigation water diverted from water source measurement done by current meter to obtain mean velocity and used in standard formula ($Q=A*V$). For this measurement the volume of marked point was calculated from water depth and cross-sectional area between two marked points (velocity area method). Then after water conveyance efficiency was computed.

3.9.1.2. Application efficiency

Application efficiency from each plot was determined from water stored in root zone from irrigation event in weight base was collected and converted to volume base multiplying by its respective soil bulk density and then multiplied by plot area, and depth of soil layer.

Those were done at three depths 0-30cm, 30-45 cm and 30-60 cm and then averaged. Data collections were done at each crop growth stage.

Volume of irrigation water stored in the root zone 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. Volume of irrigation water delivered to farm or field was taken from discharge which was measured at field channel (flow which reaches the command area of the selected plot) by Parshall flume. From these two parameters water application efficiency was computed for the nine plots.

It is expressed as:

$$E_a = \frac{V_s}{V_f} * 100 \quad (3.13)$$

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 or ha-m)

3.9.1.3. Application uniformity

For computing average depth of water infiltrated over the field (D_{av}), moisture content of the field was measured before and after irrigation. Their difference and mean of their difference were calculated. For computing average depth of water infiltrated in the low one-quarter of the field (D_{lq}), moisture content of the field was measured before and after irrigation. Their difference was calculated for the least four from descending order and then mean of their difference was computed. From D_{av} and D_{lq} distribution uniformity (D_u) were computed for the nine plots (by dividing mean of difference of overall sample for mean of difference of least quarter) as shown in the above equation.

It was expressed as:

$$D_u = \frac{D_{lq}}{D_{av}} * 100 \quad (3.14)$$

where, D_u =Distribution Uniformity (%)

D_{1q} =Average depth of water infiltrated in the low one-quarter of the field (m)

D_{av} = Average depth of water infiltrated over the field (m)

3.9.1.4. Water storage efficiency

Volume of water at field capacity (V_{fc}) in the crop root zone was determined from soil sample taken from the nine plots by using pressure plate apparatus. Volume of water in soil root zone prior to irrigation event (V_a) and Volume of water stored in the soil root zones from an irrigation event (V_s) was measured by taking irrigated soil sample from nine plots and drying it by oven for 24 hr at 105°C. Volume of water in soil root zone prior to irrigation event was computed by taking soil sample from selected plot before irrigation. Water storage efficiencies were done for nine plots, three plots from each station. For computing E_s data average of soil moisture status prior to irrigation, at field capacity and after irrigation for initial, development, mid-season and late growth stage of the crop development stage at the depth of 0-30cm, 30-45 and 30-60 cm were done and the average of the three depth and crop growth stages were taken.

Soil water storage efficiency (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 is expressed as

$$\begin{aligned}
 E_s &= \frac{V_s}{V_{fc} - V_a} * 100 \\
 E_s &= \frac{V_s}{V_{fc} - V_p} * 100 \\
 E_s &= \frac{\theta_{ai} - \theta_{bi}}{\theta_{fc} - \theta_{bi}} \quad (3.15) \\
 E_s &= \frac{V_{ai} - V_{bi}}{V_{fc} - V_{bi}} * 100 \\
 E_s &= \frac{W_{ai} - W_{bi}}{W_{fc} - W_{bi}} * 100
 \end{aligned}$$

where,

E_s = Soil water storage efficiency (%)

V_s = Volume of water stored in the soil root zones from an irrigation event (m^3/s)

V_{fc} = Volume of water at field capacity in the crop root zone (m^3/s or ha-m)

V_a = Volume of water in soil root zone prior to irrigation event (m^3/s or ha-m)

θ_{bi} = Soil Moisture before (prior to) irrigation in weight bases (%)

θ_{ai} = Soil Moisture after irrigation in weight base (%)

θ_{fc} = Soil Moisture at field capacity in weight bases (%)

W_{bi} = Weight of soil moisture before irrigation

W_{ai} = Weight of soil moisture after irrigation

3.9.1.5. Depletion fraction (DF)

To compute (DF) nine samples from each station were collected. Data were collected from soil depth 0-30 cm and 30-60 cm. From collected samples moisture content of the i^{th} layer at field capacity before irrigation and moisture content of the i^{th} layer of the soil before irrigation on dry weight basis were collected. Based on these data SMD was determined and summed up for each station.

For determining soil depletion fraction of the study area soil moisture contents before irrigation and at field capacity were determined. Three samples from each plot and total of 27 samples were taken for determination of soil moisture status before irrigation at Field capacity at depth of 300, 450, and 600mm and their average was taken for each plot at every crop growth stage. Soil moisture status before irrigation was taken at the same depth and every crop growth stage for each selected plot were collected.

The depletion fraction before the initial irrigation was calculated using the ratio of the soil moisture deficit (SMD) to TAW (equation 3.10).

$$DF = \frac{SMD}{TAW} \quad (3.16)$$

where:
$$SMD = \sum_{i=1}^n 1000(WFC_i - Wb_i) * AS_i * D_i \quad (3.17)$$

SMD=soil moisture deficit within root zone below field capacity before irrigation (mm)

WFC_i =moisture content of the i^{th} layer of the soil at field capacity of oven dry weight basis

Wb_i = moisture content of the i^{th} layer of the soil before irrigation on dry weight basis

D_i = root depth (m)

AS_i =apparent specific gravity of i^{th} layer of soil

TAW=Total Available Water (mm/m)

3.9.1.6. 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;

$$RR = \frac{D_r}{D_a} * 100 \quad (3.18)$$

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)

To do this Parshall flume was installed at the tail of each selected plot and measurement was taken until runoff stopped. Pit which had known volume was also dug to collect runoff water.

ii. Deep percolation fraction (DPF)

Deep percolation fraction (DPF) was calculated using the following equation (Walker, 2003);

$$DPF = \frac{D_d}{D_a} * 100 \quad (3.19)$$

where, D_d = depth of deep percolation (mm)

D_a =total depth of water applied to the field (mm)

Deep percolation fraction (%) could be calculated indirectly from the measured values of application efficiency (E_a) and runoff ratio (RR) as given by FAO (1989);

$$DPF = 100 - E_a - RR \quad (3.20)$$

3.9.2. 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 equation 3.21 as shown below.

$$WUE = \frac{Y_a}{ET_c} \quad (3.21)$$

where, WUE = water use efficiency (kg/m³)
 Y_a=actual yield (kg/m²)
 ET_c= seasonal crop evapotranspiration (m³/m²)

$$IWUE = \frac{Y_a}{IW} \quad (3.22)$$

Where, IWUE- irrigation water use efficiency (kg/m³)
 Y_a - actual yield (kg/m²)
 IW - irrigation water applied (m³/m²)

3.10. 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,

$$SIA = \frac{AC}{AI} \quad (3.23)$$

where: AC= current total irrigated area (ha)

AI= total irrigated area when the system development way completed (ha)

SIA=sustainability of irrigated area

3.11. Comparison of Performance of the Schemes

The efficiency data which were collected from the station-1, station-2 and station-3 were compared with each other for determining which was performing well and to see whether they had significance difference or not. Comparative indicators which included were: conveyance efficiency, application efficiency, application uniformity, water storage efficiency, depletion fraction (DF), and irrigation water losses. The mean of each of the three stations were compared statistically. The experiment was designed by CRBD using ANOVA table and mean of the stations comparison was done by Least Significance Difference.

3.12. Redesign and Maintenance of the Scheme

Redesign was aimed as conveyance efficiency of the scheme was poor and has significant runoff loss. To carry out this observation of scheme structures has been done and proper functionality of structures as per the design; tail water runoff, seepage losses and deep percolation losses were observed. The maximum demand was selected at crop developmental stage and was computed. This computed value was compared with the capacity of the canal and redesign was done for whether the scheme is under performing or over performing. Design of damaged or not working properly canals starting from main canal to field channel which will be done based on design criteria for the improvement of the performance of the scheme. This activity was carried out either the scheme is under performing or excess water is being applied to the crop. For redesigning earthen canal by lined, Manning equation was used flow rate calculated. If the flow rate is sufficiently close to the desired maximum discharge value, the design process will be finished. If the flow rate is not the desired value, change will be made to the side slope, m , and or bed width, b , checking the m and b/h limits which may have set initially. Design of lined canal was made based on amount of irrigation water loss from conveyance, tail water runoff and deep percolation, for increasing irrigable area of the scheme.

That design also depends on peak demand of the study area crop. For redesigning the scheme Manning equation and Chezy equation (applied successfully on steeper slope) were used.

$$Q = \frac{1}{n} AR^{\frac{2}{3}} S^{\frac{1}{2}} \text{ (Manning equation)} \quad (3.24)$$

$$Q = CA\sqrt{RS_o} \text{ (Chezy equation)} \quad (3.25)$$

where ,Q=Discharge through the canals(m³/s)

A=Cross sectional of flow area (m²)

N=Manning coefficient

S_o=Longitudinal slope (%)

R=Hydraulic radius (the ratio of cross sectional area and wetted perimeter)

C =Chezy's coefficient (0.60-0.69)

➤ Design Daily Irrigation Water Requirement (DDIRp)

$$DDIR = \frac{RAW}{T_{\min}} = \frac{AD}{T_{\min}} \quad (3.26)$$

Where, DDIR=Design Daily Irrigation Water Requirement

RAW=Readily Available water (mm)

T_{min}=Minimum Interval (days)

AD=Allowable Depletion (mm)

Redesign was done for conveyance loss of the scheme. It was determined from conveyance loss from diversion up to reservoir. For determining conveyance loss of the scheme, it was observed from diversion to Ketar-1, Ketar-2 then Ketar-3. To determine conveyance loss at Ketar-2 loss determined at Ketar-1 was deducted and for Ketar-3 loss at Ketar-2 was deducted. In case of Ketar-3, measurement was done when water level reached constant point. Over all loss=Ketar-1+ (Ketar-2-Ketar-1) +(Ketar-3-Ketar-2).

Design of Reservoir (night storage) for Ketar-3 or tail scheme was done due to siltation effect of the former one. An irrigation reservoir is defined as “an irrigation water storage structure made by constructing a dam, embankment, pit, or tank” (NRCS, 2011). Storage reservoirs can provide a consistent supply of irrigation water, provide storage for farms with tail water recovery, and reduce energy costs. These reservoirs are used in cases where

pumps are insufficient to provide enough water for irrigation requirements, where water can be taken from streams, surface runoff, or groundwater. In order for a reservoir to be useful, the existing water supply must be insufficient to meet crop requirements, water is available for storage from some source and a site is available for the reservoir (NRCS, 2011). Design of the reservoir was made at land which is beside the former constructed one. The shape of newly designed reservoir is trapezoidal frustum. Silt excluder was also designed before water enters the reservoir. Design capacity (size) of the reservoir (night storage) was based on the amount water which would be stored farmers could use next day.

3.13. Data Analysis

Collected data concerning soil physio-chemical characteristics was analyzed. CROPWATmodel-8 was used for processing meteorological data and for determination of crop water requirement of the selected plot. Data which collected 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 using Least Significance Difference (LCD) used for comparing.

4. RESULTS AND DISCUSSION

4.1. Scheme Characterization

Ketar medium scale irrigation scheme is diverting from Ketar River which feeds Lake Ziway. It has flume which conducts the water to steep hill side as there is gully nearby diversion weir. The scheme was designed for 400ha with design discharge of 860l/s ($0.86\text{m}^3/\text{s}$), which means designed water discharge is 2.15 l/ha. But current observed discharge was $0.80\text{m}^3/\text{s}$. Farmers were using this water to irrigate land which is larger than designed command area. Crops which dominantly grown are potato, onion, cabbage (*Gomen*), Head Cabbage, Carrot and Pepper. Farmers were using traditional water application as they were not applying intended amount of water which would be applied based on crop type, soil type and crop growth. Most part of the scheme is earthen canal even the main canal, which leads to seepage and deep percolation loss of water before it reaches farmers' field. This project was constructed by government and rehabilitated by OIDA in cooperation with JICA. There was no enough data available on the design of the scheme. From observation done for the project there are broken canal through which conveyance loss occur and there was mismanagement of water particularly gates were not closed after use which cause discharge reduction for the next user and shortage of water which reach night storage during night.

Table 2. 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 3. Quantity and length of structures of Ketar scheme

No	Particular	Number /quantity			Length (m)		
		Ketar-1	Keta-2	Ketar-3	Ketar-1	Keta-2	Ketar-3
1	Division box	5	10	1	-	-	-
2	Irrigation pond	1	1	12	-	-	-
3	Main canal	1	1	1	-	3170	-
4	Secondary canal	6	2	1	3653	5930	1670
5	Tertiary canal	-	7	1	-	1943	3690
6	Area boundary	7	10	12	8540	-	-
7	Farm boundary	1	1	1	653	-	-
		-	1	-	-	-	-

Table 4. Irrigated area and Users (H/H) of Ketar Irrigation Scheme rehabilitated by Community and OWRB with JICA cooperation (2000 E.C, 2008)

Sub Station	Stations=>	Area (ha)			H/H		
		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

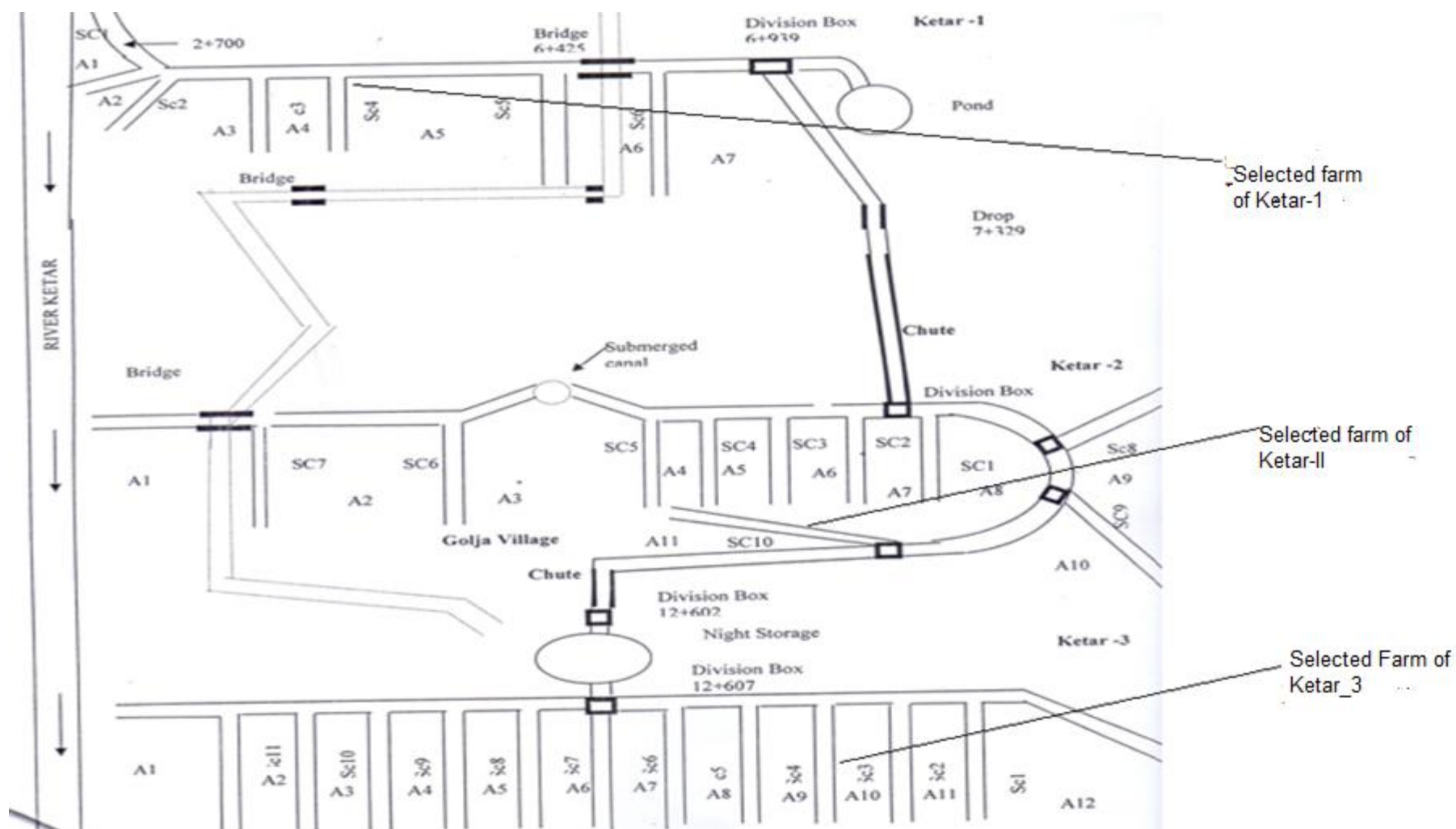


Figure 3. Layout of Ketar Irrigation Scheme Stations

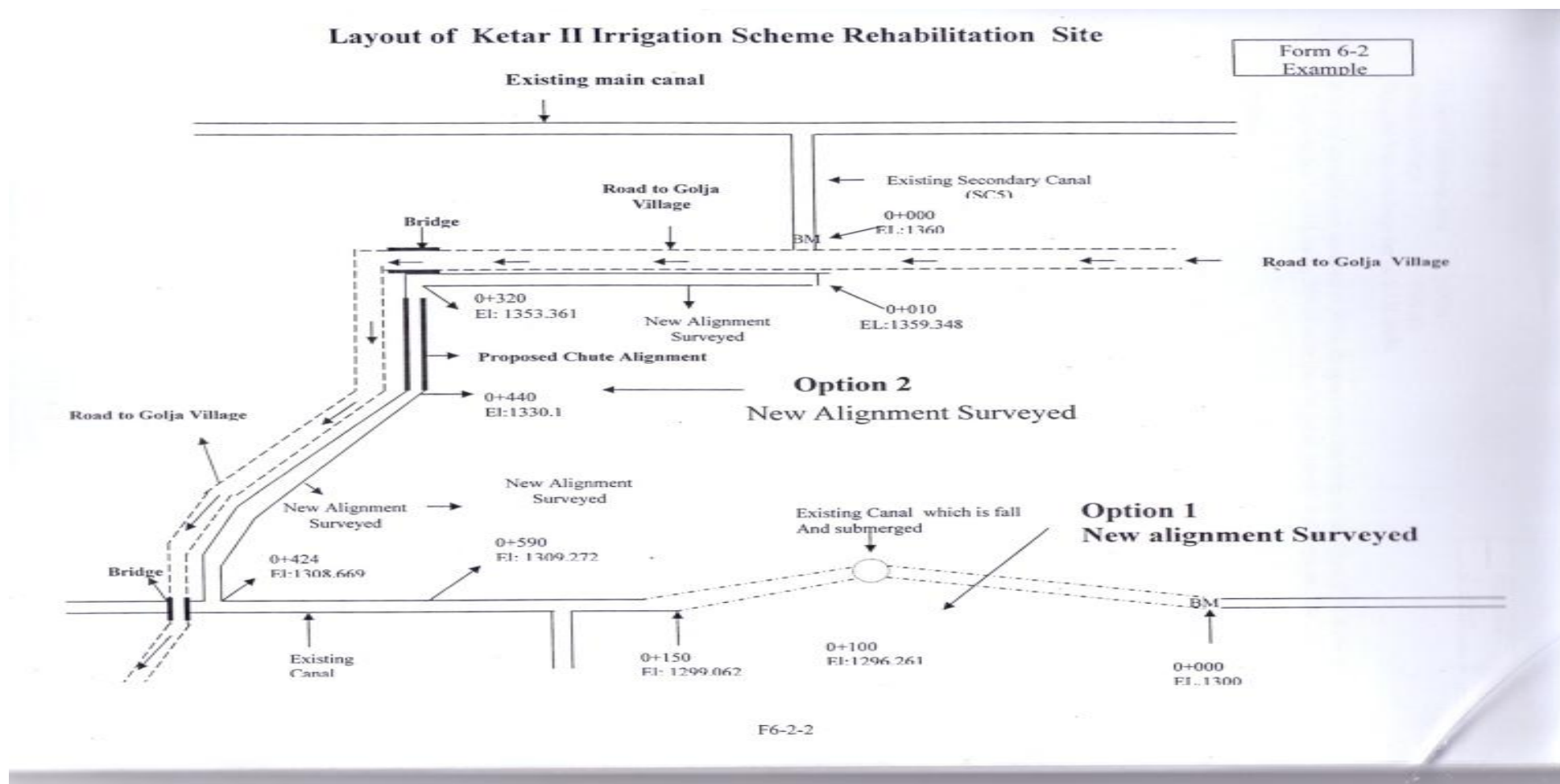


Figure 4. Layout of rehabilitated Ketar Scheme at Ketar-2

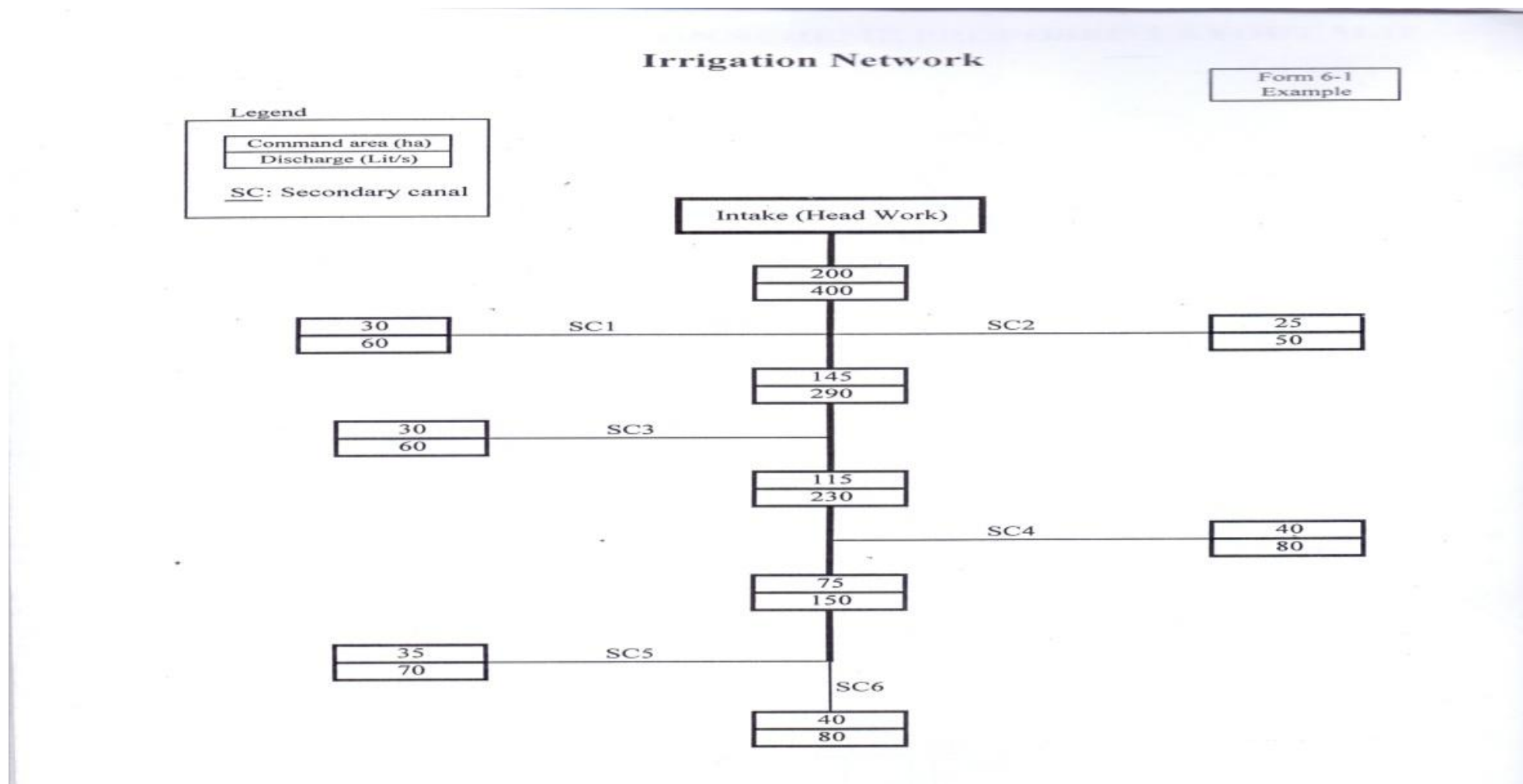


Figure 5. Irrigation Network of Ketar Irrigation Scheme rehabilitated by Community and OWRB with JICA cooperation, 2000E.C (2008GC)

4.2. Crop Water Requirement and Irrigation Water Requirement

Planting dates were January 11, 14, 16, 23, 25, 23, 06, 03 and 11, 2016 for plots 1 up to 9 respectively three plots from each station (Ketar-1, Ketar-2 and Ketar-3) situated at head, middle and tail of Ketar medium scale irrigation scheme. Necessary parameters, like minimum and maximum temperature, relative humidity, wind speed and daily sunshine hour of the study area were collected from Chebi Meteorological Station, which is nearby to the study area and National Meteorological Agency. Average ET_c value of 19 years (1997-2015) of the study area was 4.43mm/day for Potato from January-May at Chebi Meteorological station. Net and gross irrigation requirement was 463.4mm for Potato from for one season (January to May).

Table 5. ET_c computation for Potato using CROWAT Model-8
Station –Chebi, Altitude-1544m, Latitude- 7.83°, Longitude- 39.03°

Month	Decade	Stage	Kc Coeff	ET_c mm/day	ET_c mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jan	2	Init	0.5	2.13	17	4.7	11.2
Jan	3	Init	0.5	2.18	24	9.7	14.2
Feb	1	Deve	0.52	2.33	23.3	14.7	8.6
Feb	2	Deve	0.72	3.26	32.6	18.3	14.3
Feb	3	Deve	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

According to Sood and Singh (2003), Potato requires 0.35 to 0.8 m³ of water to produce 1 kg of tuber dry matter. Under field conditions, this translates into a water requirement 350 to 650 mm during growing period, which is dependent on climate and cultivar. Estimated

irrigation requirement for Ketar, which was 463.4, was in the range of the one studied by Sood and Singh,(2003).

4.3. Inflow and Outflow Water Measurements at Field

To compute the volume of water used by selected farmers, irrigation duration (how long they irrigate) had been collected from each farmer.

Table 6.Observed discharge of flow at Ketar diversion head work

Distance (m)	Depth (m)	Velocity (m/s)	Mean velocity (m/s)	Width (m)	Mean depth (m/s)	Segment Discharge (m ³ /s)
0	0	0	0	0	0	
			0.628	0.4	0.265	0.067
0.4	0.53	1.256				
			1.6705	0.4	0.54	0.361
0.7	0.55	2.085				
			1.619	0.4	0.53	0.343
1	0.51	1.153				
			0.5765	0.2	0.255	0.029
1.2	0	0	0			
Total Discharge						0.800

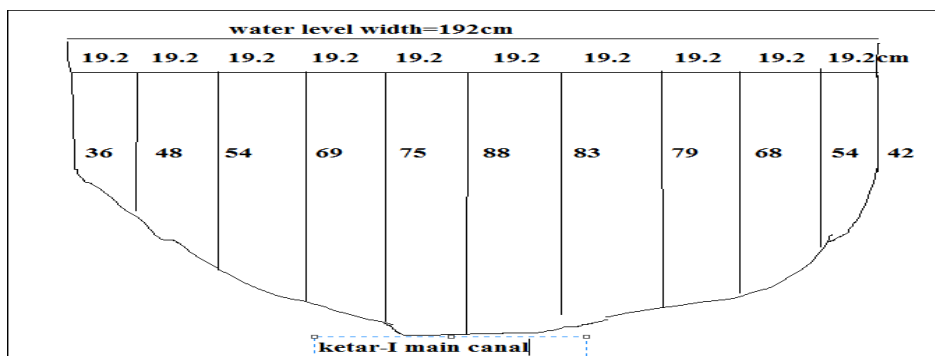


Figure 6. Cross sectional of Ketar-1 main canal

Table 7.Observed discharge of flow at ketar-1main canal

Distance (m)	Depth (m)	Velocity (m/s)	Mean velocity (m/s)	Width (m)	Mean Depth (m)	Segment Discharge (m ³ /s)
0	0	0	0	0	0	0
			0.1155	0.192	0.18	0.004
0.192	0.36	0.231				
			0.2915	0.192	0.42	0.023
0.384	0.48	0.352				
			0.4295	0.192	0.51	0.042
0.576	0.54	0.507				
			0.5395	0.192	0.615	0.064
0.768	0.69	0.572				
			0.6165	0.192	0.72	0.085
0.96	0.75	0.661				
			0.6435	0.192	0.815	0.101
1.152	0.88	0.626				
			0.5685	0.192	0.835	0.091
1.344	0.79	0.511				
			0.487	0.192	0.735	0.069
1.536	0.68	0.463				
			0.405	0.192	0.61	0.047
1.728	0.54	0.347				
			0.1735	0.192	0.27	0.009
1.92	0	0	0			
Total Discharge						0.535
$E_c = 0.535/0.799 \times 100 = 66.96\%$						

Table 8.Observed discharge of flow at ketar-1 secondary canal

Distance (m)	Depth (m)	Velocity (m/s)	Mean velocity (m/s)	Width (m)	Mean depth (m)	Segment Discharge (m ³ /s)
0	0	0		0		
			0.329	0.1	0.26	0.008
0.1	0.52	0.658				
			0.741	0.2	0.53	0.078
0.3	0.54	0.823				
			0.558	0.4	0.505	0.113
0.7	0.47	0.293				
			0.146	0.1	0.235	0.003
0.8	0	0				
Total Discharge(m ³ /s)						0.202

Ketar-2 main canal discharge was 0.452 m³/s. Ketar-2 secondary discharge was 0.057 m³/s. Main canal of Ketar-3 is rectangular canal 0.75m width and 0.25m water level height (H). Using discharge measurement by structure formula for rectangular notch (sharp crested rectangular opening is $(Q = \frac{2}{3} c_d \sqrt{2g} L H^{3/2})$ where c_d (coefficient of discharge) value is 0.60-0.69. Discharge at this point was 0.391m³/s (Table 8). This value was greater than Ketar-2 main canal because Ketar-2 was continuous flow where as this one is from reservoir and its flow duration depends on amount of water in the night storage and there were many users than in Ketar-2. Discharge of Ketar-3 secondary canal was computed in Table below by mean velocity method.

Table 9. Observed discharge at Ketar-2 main and secondary canals and Ketar-3 main canal

Structure place	Canal type	Canal Shape	Water level Top width (m)	Bottom width (m)	Average flow depth (m)	Section discharge (m ³ /s)
Ketar-2 main canal	Lined	Trapezoidal	2.00	1.66	0.58	0.452
Ketar-2 secondary canal	Lined	Rectangular	0.40	0.40	0.17	0.057
Ketar-3 main canal	Lined	Rectangular	0.75	0.75	0.403	0.391

Table 10. Observed discharge of flow at Ketar-3 secondary canal

Distance (m)	Depth (m)	Velocity (m/s)	Mean velocity (m/s)	Width (m)	Mean depth (m/s)	Segment Discharge (m ³ /s)
0	0	0	0.000	0	0	
			0.087	0.27	0.05	0.001
0.15	0.1	0.173	0.242	0.27	0.14	0.009
0.3	0.18	0.31	0.732	0.27	0.195	0.039
0.45	0.21	1.153	0.750	0.27	0.205	0.042
0.6	0.2	0.347	0.322	0.27	0.185	0.016
0.75	0.17	0.297	0.000		0	
Total Discharge						0.106

Table 11. Discharge observed using 3'' Parshall Flume at field channel

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	

4.4. Physio-Chemical Properties of Soil

Soil pH values were found in range of 5.31-5.88 and is indicating moderate acidic soil. Electrical conductivity (EC) of the stations was in range of 0.16-0.49 mmhos/cm at room temperature (25°C) respectively. Average organic matter contents (OM) of the station was in range of 2.77-3.98. It was concluded that the scheme soil was clay loam and had average values of 5.56, 0.34 mmhos/cm 3.44 for pH, Electrical conductivity and organic matter content values respectively (Table 12). 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.

Table 12. Soil Chemical Characteristics of the Ketar Scheme

Station	PH	EC (mmhos/cm at 25°C)	OC (%)	**OMC	Soil texture			
					Sand (%)	Silt (%)	Clay (%)	Class
Ketar-1	5.88	0.49	2.31	3.98	36	24	40	Clay
Ketar-2	5.49	0.16	2.08	3.58	31	32	37	Clay loam
Ketar-3	5.31	0.38	1.60	2.77	36	30	34	Clay loam
Ketar Scheme (Average)	5.56	0.34	2.00	3.44	34	29	37	Clay loam

4.7. Irrigation Efficiencies

4.7.1. Conveyance efficiency

By using mean velocity method discharge measured at diversion head and Ketar-1 main canal were found as 0.800 and 0.535, m³/s, respectively. Conveyance efficiencies were found as 66.86, 56.50 and 48.90% at Ketar-1, Ketar-2 and Ketar-3 main canals, respectively. Conveyance efficiency of the scheme was estimated as 57.40% (Table 15). The Table related to conveyance efficiency indicates that there was seepage loss of irrigation water. As stated by FAO, (1989), for earthen canal length >2000m constructed on clay soil its conveyance efficiency would be 80% where as 95% for lined canal. From that result it is concluded that conveyance efficiency of Ketar scheme was poor.

Table 15. Summary of irrigation performance indicators

Efficiency Parameters =>	Convey- ance Efficien cy (%)	Storage Efficien cy (%)	Applicat -ion Uniformi ty (%)	Applicati on Efficienc y (Ea) (%)	Runoff Ratio (RR) (%)	Deep Percolati on Fraction (DPF) (%)	Irrigatio n Water Use Efficien cy (kg/m ³)	Depleti on Fractio n (%)
Stations								
Ketar-1	66.90	202.20	59.98	57.19	34.75	8.06	2.13	72.80
Ketar-2	56.50	141.30	64.78	65.51	25.33	9.16	2.79	69.10
Ketar-3	48.90	136.50	60.03	62.10	23.51	14.39	2.23	68.5
Scheme	57.40	160.00	61.60	61.60	27.86	10.54	2.38	70.10

4.7.2. Application efficiency

Average application efficiency of the stations indicated that, it was in range of 57.19 and 65.51%. Average application efficiency of the scheme was 61.60% (Table 15). 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). As stated by Michael (2008), water application efficiency below 100 percent is due to seepage losses from the field distribution channels and deep percolation below the crop root zone. 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), application efficiency for surface irrigation is 60%. Based on this, Ketar-1 was not efficient, whereas Ketar-2 and 3 were efficient.

4.7.3. Application uniformity

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 (Table 15).

4.7.4. Water storage efficiency

From data collected and mean taken at three depths, namely 0-30, 30-45 and 45-60cm, average water storage efficiency (E_s) were 202.2%, 141.3% and 136.5% for Ketar-1, Ketar-2, Ketar-3, respectively. It was 160.0 % for the scheme (Table 15). That showed as farmers in up and middle stream were using excess water, whereas farmers in down stream facing deficiency of water even some times soil moisture content become less than field capacity. According to Michael (2008), the importance of determining storage efficiency is that, when water supplies are limited or when excessive time is required to secure adequate penetration of water into the soil.

4.7.5. Depletion fraction (DF)

From three soil samples collected from each station average depletion fractions were found as 72.80, 69.10 and 68.50 % for Ketar-1, Ketar-2, and Ketar-3, respectively. An average depletion fraction of the scheme was 70.10 % (Table 15). 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.

4.7.6. Irrigation water losses

a. Runoff ratio (R.R)

From measurements taken by Parshall flume at four crop growth stages, average runoff ratio of stations were 34.75, 25.33 and 23.51% for Ketar-1,2 and 3, respectively. Mean runoff ratio of the scheme was 27.86% (Table 15). This result indicates that the scheme had more runoff loss than deep percolation because the soil type was clay loam.

If this water is re-used it can represent a significant supplemental supply compared with allowing the runoff to leave the farm. Generally, a common collector ditch can be used across the bottom of the field to channel the water into the headland facilities of a down slope field, or into a small pond for storage and later use. In case of the study area on which this research was conducted, there no such practice to reuse that runoff.

b. Deep percolation fraction (DPF)

Average results of deep percolation fraction for stations were 8.06, 9.16, and 14.39% Ketar-1, Ketar-2 and Ketar-3, respectively. Mean of the scheme deep percolation fraction was 10.54 (Table15). 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.

4.7.7. Water productivity and relative irrigation supply of the scheme

From water applied to the farm throughout the growing season of the selected crop (Potato) and yield harvested from each plot, irrigation water use efficiencies were 2.13, 2.79 and 2.23 kg/m³ for station 1, 2 and 3, respectively. Average productivity which was expressed by irrigation water use efficiency was 2.38 kg/m³(Table 15). According to Sood and Singh (2003), Potato requires 0.35 to 0.8 m³ of water to produce 1 kg of tuber dry matter. This implies that water productivity is 1.25-2.86 kg/m³. As ketar scheme water productivity was 2.38 kg/m³ it was in the range of study done by Sood and Singh (2003).

4.8. Sustainability of Irrigation System

The design and efficiency of main canal is the main decisive variable for sound water management. From study conducted sustainability of the scheme was 1.26 (Table 16). Current command area is 26% greater than the designed one. This study indicates as users

are irrigating much area than the designed one. To be sustainable there should be 1:1 ratio of designed and current command area. Additionally, as stated by Cai *et al.*, 2001, sustainable irrigation water management should simultaneously achieve two objectives: sustaining irrigated agriculture for food security and preserving the associated natural environment. Therefore, even water users' livelihood is improving, Ketar irrigation scheme has no soil and water conservation activity which exposes night storage located in downstream for siltation.

Table 16. 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

4.9. Comparison of Performance of the Schemes

Upper and middle stream users were consuming more water than lower one, but there were more households in lower stream than the two streams. That was checked statistically by ANOVA and Duncan Multiple Range Test as shown below.

From ANOVA test, there is no significant difference in mean of application efficiency, storage efficiency, application uniformity, runoff ratio and deep percolation ratio among the stations at 5% and 10% significance level among the stations, but there was significance difference at for IWUE at both significance levels.

Table 17. Least Significant Difference for IWUE of Ketar irrigation scheme

Station	Mean IWUE (%)	Difference
Ketar-1	2.13	Ketar -2&Ketar -1=0.66
Ketar -2	2.79	
Ketar -3	2.06	(Ketar-1)&(Ketar-3)=0.07 (Ketar-2)&(Ketar-3)=0.73
CV	9%=0.09	
LSD @ 5%	NS	
LSD @ 10%	0.69	
SE	0.16	

From the least significance difference (LSD) comparison, it is concluded that there is significant difference between IWUE mean of ketar-2 and ketar-1 and ketar-2 and ketar-3

at 10% significance level. At 5% Ketar-3, Ketar-1, Ketar-2 indicates that there is no significant difference between IWUE mean of the three stations.

4.10. Redesign and Maintenance of the Scheme

Design and efficiency of main canal was the main decisive variable for sound water management. Water was flowing long way about 8km before it reaches farmer field. That was due to topography of canal with respect to farm land. About 60% of the length of the scheme was flowing in earthen canal which has seepage loss which has great influence on conveyance efficiency of the system. Additionally, that earthen canal had been affected by weed. Estimating the crop water and irrigation requirements for a proposed cropping pattern was an essential part of the planning and design of an irrigation system. The irrigation requirement (IR) was one of the principal parameters for the planning, design and operation of irrigation and water resources systems.

Redesign was made by changing earthen canal to lined starting from diversion head work which had discharge of $0.8\text{m}^3/\text{s}$. Bed width of canal was 0.6m and average flow depth was 0.53m. Designed canal was trapezoidal using Manning formula. Side slope of the canal was 1.8:1 from data collected during characterization. From measurement taken area of wetted cross-section (A) of the canal was 9.82m^2 . Lining was designed to construct canal by concrete. Manning roughness coefficient (n) value for lined canal bed constructed from concrete is 0.017.

Redesign was aimed to construct lined canal by using conveyance loss, runoff and deep percolation losses which took place at each stations and redesign of night storage of lower/tail station as well. Estimated amount of total water loss from only runoff and deep percolation was 1,144,937.11 cubic meter per season. Average Conveyance efficiency of the scheme was 57.4 %, thus 42.6% water from diversion was conveyance loss. It was 42.4% of $0.8\text{m}^3/\text{s}$, which equals $0.341\text{m}^3/\text{s}$. Maximum seasonal crop growth length is 150 days for dominantly grown crop of Ketar scheme (Potato, Onion, and Cabbage) on clay loam soil. From this seasonal conveyance loss was $4,419,360\text{m}^3$. Conveyance efficiency of lined canal is 95%. So 95 % of $0.518\text{m}^3/\text{sec}$ ($0.492\text{m}^3/\text{sec}$) can reach farm. It is difficult to stop deep percolation loss rather runoff. Net irrigation depth for those four crops growing

at the scheme was 45mm and application efficiency of surface irrigation is 60% as stated by FAO water management manual. From that gross irrigation depth was 75mm.

Table 18. Summary of water loss in Ketar scheme

Station	Average plot area (m ²)	Average loss (m ³)	Current command area (m ²) x10 ⁴	Runoff and deep percolation loss (for 12 hours daily) (m ³)	Conveyance loss (for 24 hours daily) (m ³)	Discharge at each station (m ³ /s)	Redesigned command area(ha)
Ketar-1	1191.67	361.81	143	330939.24		0.282	188
Ketar-2	1233.33	192.13	248.5	312169.71		0.518	345
Ketar-3	1187.5	209.88	150	215093.86		0.391	262
Total	3612.5	763.82	541.5				795
Average	1204.17	254.61					
Scheme Losses(m ³ /season)				1,144,948.93	4,419.360		
Schemelossm ³ /sec)				0.177	0.341		
Total Scheme loss (m ³ /sec)				0.518			

Lining of canals was an important feature of irrigation projects as it improves the flow characteristics and minimizes the loss of water due to seepage. The water thus saved can be utilized for the extension and improvement of irrigation. According to Michael, 2008, Irrigation interval at Climate-1 was chosen since for ET_o of Ketar Scheme was 4.43mm/day (Table 18).

Canal design was made for discharge of 0.518m³/s for farm land located in Ketar-II and was out of WUA. Using Manning formula necessary parameters of the canal was computed as follow. According to FAO Irrigation Water Management, Manual 7, for lined canal constructed by concrete maximum permissible velocity and limiting side slope are 2m/s and 1.5:1, respectively. Manning roughness coefficient value for concrete lining is 0.0170 as stated by Schwab *et al.*, 1966.

Based on peak periods of water requirement on clay loam soil, net root (50mm) and minimum irrigation interval of 6days (Michael, 2008) were selected for design (Table 18). Application efficiency of surface irrigation was taken as 60%.

Table 19. Estimated irrigation schedule of common crops during peak periods in water requirement for clay loam soil (Michael, 2008)

Requirement for clay loam soil (chickens, 1999)																
Loamy Soils						Clay Loam				Clayey Soil						
		Irrigation Interval (days)		Net Irrigation Depth (mm)				Irrigation Interval (days)		Net Irrigation Depth (mm)		Irrigation Interval (days)		Net Irrigation Depth (mm)		
Climate*		1	2	3		1	2	3		1	2	3		1	2	3
1	Onion	4	3	2	20	6	4	3	25	7	5	4	30			
2	Cabbage	8	6	4	40	9	7	5	45	10	7	5	50			
3	Potato	4	3	2	20	6	4	3	25	7	5	4	30			

1=Climate 1=ET_o ranges 4-5mm/day, 2=Climate 2= ET_o ranges 6-7mm/day, 3= ClimateET_o ranges 8-9mm/day.

From crop water requirement and irrigation water requirement of crops which are dominantly grown in the scheme, canal expansion was designed. It has one secondary canal, two tertiary canals and one division box of as water reaches farm from main canal to farm which is located in Ketar-2, which was not in designed previous command area. Amount (Volume) of excess water to be reused is shown in Table 17.

The efficiency of furrow irrigation systems can often be improved by reducing the inflow rate after water has advanced to the end of the field by using a common practice is to cut back to 50% of the inflow. As lined canal has more advantages than earthen canal like insuring cross section stability from scour, low flow conditions, long economic life maintenance with, and the earthen one is to be replaced by this one. For constructing lined canal on clayey soil, recommended side slope is 1.5:1 up to 2.5:1 (Kisan *et al.*, 2000). To prevent scouring of the side of canal it is better to construct the bottom of canal curved. Side slope of 1.5:1 was selected. Design was made as shown in Table 19.

Table 20.Computed design parameters for newly designed canal

Canal section	Q (m ³ /s)	V (m/s)	N	Z (m)	S ₀	A (m ²)	R (m)	W _p (m)	d (m)	B (m)	Command area (ha)
Secondary	0.518	1.5	0.017	1.5	0.0055	0.345	0.202	1.713	0.37	0.38	345
Tertiary -1	0.217	1.500	0.017	1.500	0.0098	0.145	0.131	1.107	0.25	0.21	145
Tertiary -2	0.301	1.500	0.017	1.500	0.0080	0.201	0.152	1.318	0.26	0.38	200
										95% efficient lined canal	327.75

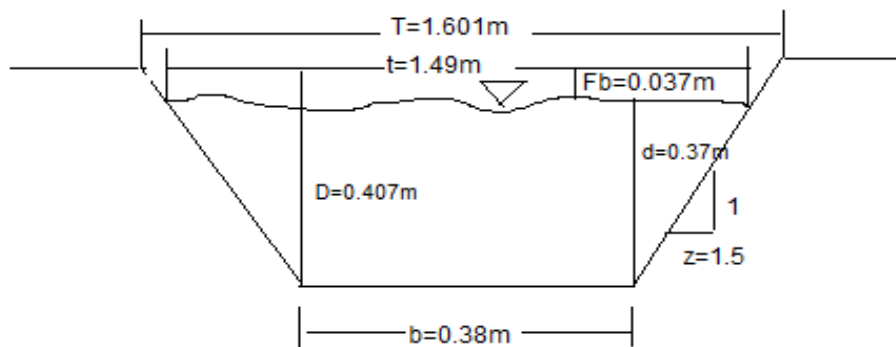


Figure 7. Cross sectional view of redesign of secondary canal

Gross irrigation depth was 75mm ($100 \cdot d_{\text{net}} / E_a = 100 \cdot 45 / 60$). Minimum irrigation interval was 6 days. 75mm every 6 days is 12.5 mm/day rounded to 13mm/day which is equal to 1.50 l/sec/ha or $1.5 \times 10^{-3} \text{ m}^3/\text{sec/ha}$ using conversion factor of 1 l/sec/ha=8.64mm/day. Design discharge was $0.518 \text{ m}^3/\text{sec}$. For irrigating an area of 1 ha, the continuous flow was $1.5 \times 10^{-3} \text{ m}^3/\text{sec}$. From this $0.518 \text{ m}^3/\text{s}$ can irrigate 345ha.

Redesign was also made for reservoir which was seriously affected by silt accumulation. Design of reservoir was made to store water which reach Ketar-3main canal which was found as $0.391 \text{ m}^3/\text{s}$. Storage time is for 12 hour during night. Based on this reservoir which has capacity $16,891.2 \text{ m}^3$ ($0.391 \text{ m}^3/\text{s} \cdot 12 \cdot 3600 \text{ sec}$) was designed. Evaporation from shallow water bodies can also be approximated by multiplying reference ET_o coefficient of 1.05 (Allen *et al.*, 1998). Thus, evaporation becomes $4 \text{ mm/day} \cdot 1.01 = 4.04 \text{ mm/day}$ or $4.04 \times 10^{-3} \text{ m/day}$ and multiplied by reservoir water surface area ($4.04 \times 10^{-3} \text{ m/day} \times (76.61 \text{ m})^2$) which is $23.71 \text{ m}^3/\text{day}$ or $0.0006 \text{ m}^3/\text{s}$. When evaporation deducted from reservoir inflow ($0.518 \text{ m}^3/\text{s}$), $0.5174 \text{ m}^3/\text{s}$. Farm which can be irrigated is also decreased to 344.93 ha.

Side slopes were set at 3:1. A 3:1 slope was chosen in order to ensure slope stability and to comply with NRCS Code 378 which states that outer slopes must be 3:1 or flatter and was used for reservoir design. To prevent seepage loss in the reservoir, covering its inner by geo membrane is recommendable. Shape of designed reservoir was truncate square prism or trapezoidal frustum whose top and bottom width are square. Designed reservoir has dimensions shown in Figure 8.

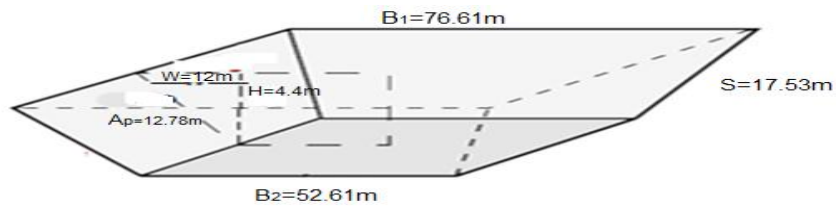


Figure 8. Isometric-View of designed reservoir truncate square prism

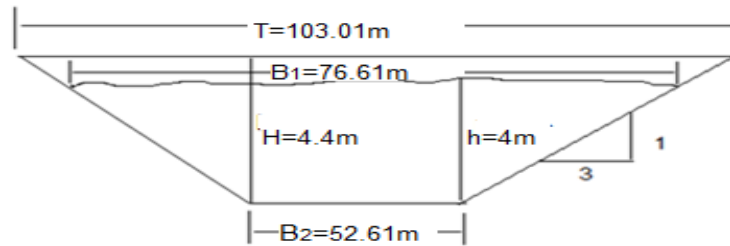


Figure 9. Cross section of designed truncate square prism reservoir

Generally, new redesigned command area can increase previously designed command area which was irrigating 431.50 hectare can increase to 795 hectare. This can be achieved by applying right amount of water at right time based on each crop water requirement grown on the command area by guide of experts, by avoiding miss management of water by WUA and managing loss by conveyance, runoff and deep percolation.

5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1. 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. Study conducted on Ketar medium scale irrigation was based on irrigation performance indicators such as conveyance efficiency, application efficiency, storage efficiency, application uniformity, runoff ratio, and deep percolation fraction and irrigation water use efficiency. Average Conveyance efficiency of stations was 66.90, 56.50 and 48.90 % for Ketar-1, Ketar-2 and Ketar-3, respectively and it was 57.40% for the Ketar Scheme. The scheme was designed for 400ha with design discharge of 860l/s ($0.86\text{m}^3/\text{s}$), which means designed water discharge of 2.15 l/ha. But current (measured) discharge was 800 l/s ($0.800\text{m}^3/\text{s}$). Application efficiency of the stations were 57.19, 65.51 and 62.10 for Ketar-1, 2 and 3 respectively. Average application efficiency of the scheme was 61.60%. Application uniformities were 59.98%, 64.78% and 60.03% for Ketar-1, Ketar-2, Ketar-3 respectively and was 61.60% for the scheme. Average storage efficiencies were 202.2%, 141.3 % and 136.5% for Ketar-1, Ketar-2 and Ketar-3 respectively. Average scheme storage efficiency was 160.0%. Average depletion fractions were found as 72.80, 69.10 and 68.50% for respective stations and for scheme was 70.10%. Average station runoff ratio were found as 34.75, 25.33 and 23.51% for Ketar-1, 2 and 3 consecutively and was 27.86 for the scheme and average deep percolation fractions of consecutive stations were 8.06, 9.16, and 14.39%. Based on ANOVA test and Duncan Multiple range test, there was significant difference among stations in irrigation water use efficiency at 5% and 10% significant level, while there was no significance difference for storage efficiency and application uniformity at both significance levels. Design of lined secondary canal with flow of $0.518\text{m}^3/\text{s}$ was made. New reservoir of capacity $26,891.2\text{m}^3$ was also designed.

Soils with moderate to low infiltration rates (loams and other fine textured soils) are better for surface irrigation. Soil of the study area was clay loam which had higher water holding capacity and was best suited for surface irrigation than other sandy soils. This soil needs more water at each irrigation period and it can be retained more days than as in case of

sandy soil. Such type of soil has also low deep percolation as shown in the study as well. As irrigation frequency is a function of crop, soil and climate (Michael, 2008), so such type of soil needs more days interval to irrigate but irrigation period should be take more hour to fill soil pore space with water than other soils which helps to irrigate.

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 junctions and loss of water flow about 9km before starting use of first water drop as been indicated from conveyance efficiency test. Current command area is greater than designed command area and farmers in downstream are facing shortage of water.

There is miss management of water in scheme particularly in up and middle stream. Night storage constructed in Ketar-3 was affected by silt. Based on observed problems design was made to change earthen canal to lined canal in order to reduce seepage, canal expansion to reuse tail water loss and seepage loss and therefore, new reservoir is suggested and designed for Ketat-3.

In general, water application efficiency decreases as the amount of water applied during each irrigation increases. The study had shown that the scheme is not efficient technically as it has high storage efficiency and low application efficiency. It has lower deep percolation loss than run off loss. Redesign activities done so far were changing earthen canal which starts nearby the diversion weir, extension of secondary canals based on estimated water loss by seepage, spillage, runoff and deep percolation and design of new night storage instead of the previously silt affected one.

5.2. Recommendations

Application of right amount of water at right time is the most necessary in irrigation field as both under irrigation and over irrigation have their own outcome on crop which is to be irrigated.

It is recommendable to use water which reach farm to increase water productivity and to reduce water loss by using much irrigation frequency as soil of study area has high water holding capacity.

It is better to change earthen canal to lines on as lined canal reduces seepage loss, which saves of water which can be utilized for additional irrigation, prevent water logging by reducing seepage to water-table and improvement of operational efficiency. In addition if lined canal is used command area can be increased and weed can be controlled. It is also necessary to give awareness for farmers how to apply right amount of water at right time.

To reduce siltation problem of Ketar-3 night storage soil and to increase discharge of the scheme it is recommendable to do water shed 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.

Fields should have a uniform grade in the direction of water flow to obtain best results. A uniform grade or level surface prepared through precision land leveling helps to provide equal infiltration opportunity times.

Furtherresearchwork is required adequately to use irrigation water properly as now and more in the future water scarcity is a bottle neck for crop production due to climatic change.

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7. APPENDIX

7.1. Appendix Tables

Appendix Table 1. Potato Crop irrigation Schedule of Ketar scheme

Station –Chebi,		Altitude- 1544m,		Latitude- 7.83°, Longitude- 39.03°							
Date	Day	Stage	Rain Mm	Ks fract.	Eta %	Depl %	Net Irr Mm	Deficit mm	Loss Mm	Gr. Irr mm	Flow l/s/ha
13-Jan	1	Init	2.9	0.74	74	48	26.1	0	0	37.3	4.32
20-Jan	8	Init	0	1	100	25	15.5	0	0	22.1	0.37
31-Jan	19	Init	0	1	100	26	19.1	0	0	27.3	0.29
16-Feb	35	Dev	0	1	100	30	26.1	0	0	37.3	0.27
26-Feb	45	Dev	0	1	100	29	28.1	0	0	40.1	0.46
10-Mar	57	Mid	0	1	100	34	37.1	0	0	53	0.51
20-Mar	67	Mid	0	1	100	30	32.7	0	0	46.7	0.54
29-Mar	76	Mid	0	1	100	30	32.9	0	0	47	0.6
5-Apr	83	Mid	0	1	100	35	37.3	0	0	53.3	0.88
12-Apr	90	Mid	0	1	100	35	37.5	0	0	53.5	0.88
18-Apr	96	Mid	0	1	100	33	35.7	0	0	51.1	0.98
25-Apr	103	End	0	1	100	36	39.4	0	0	56.2	0.93
4-May	112	End	0	1	100	42	45.1	0	0	64.4	0.83
16-May	124	End	0	1	100	47	50.8	0	0	72.5	0.7
22-May	End	End	0	1	0	19	0			0	0
Total							463.4			661.8	

Appendix Table 2. Computation of water content, bulk density and volumetric moisture content of Ketar irrigation scheme

station		Ketar-1							Ketar-2							Ketar-3										
P lo t	Sam- ple	W _t (g)	W _s (g)	W _w (g)	V _{cs} (cm ³)	ρ _b (g/c m ³)	W (%)	θ (%)	W _t (g)	W _s (g)	W _w (g)	V _{cs} (cm ³)	ρ _b (g/cm ³)	W (%)	θ (%)	W _t (g)	Ws (g)	W _w (g)	Pb(g/c m3)	W (%)	θ (%)					
1	1	145.95	104.2	41.75	98.13	1.06	39.69	42.49	135.85	93.4	42.45	98.13	0.95	45.66	43.25	124.00	107.05	21.3	1.1	20.02	21.8					
	2	124	107.05	21.3	98.13	1.09	20.02	21.71	133.35	100.1	33.25	98.13	1.02	33.25	33.89	125.6	107.4	18.2	1.09	16.81	18.47					
	3	143.95	109.2	34.75	98.13	1.11	30.85	35.42	144.1	103.55	40.55	98.13	1.06	39.23	41.32	128.35	103.3	25.05	1.06	24.1	25.59					
	4	140.95	119.95	21	98.13	1.22	17.58	21.35	140.7	106.4	34.3	98.13	1.08	32.06	34.96	135.25	106.3	28.95	1.08	27.2	29.42					
	5	129.15	107.65	21.5	98.13	1.09	10.98	21.77	139.85	111.25	28.6	98.13	1.13	25.63	29.15	127.05	104.85	22.2	1.07	21.07	22.65					
Av							1.11	23.82	28.55						1.05	35.17	36.51						1.08	21.84	23.59	
2	1	142.85	107.6	35.25	98.13	1.1	32.97	35.86	131.95	100.35	31.6	98.13	1.03	31.43	32.2	128.05	106.15	21.9	1.08	20.57	22.29					
	2	147	110.95	36.05	98.13	1.13	32.48	36.72	138.2	110.7	27.5	98.13	1.13	24.63	28.03	124.85	107.6	22.25	1.10	21.1	22.61					
	3	156.5	124.85	31.65	98.13	1.27	25.41	32.19	139.6	117.7	21.9	98.13	1.20	18.62	22.32	128.7	109.15	19.55	1.11	17.97	19.88					
	4	146.35	123.5	22.85	98.13	1.26	18.52	23.22	138.3	106.55	31.75	98.13	1.09	29.65	32.36	129.25	114.25	15	1.16	13.12	15.23					
	5	150.8	124.9	25.9	98.13	1.27	20.73	26.37	122.75	104.35	18.4	98.13	1.07	17.54	18.75	131.6	106.9	24.7	1.09	22.93	25.19					
Average							1.21	26.02	30.87						1.10	24.37	26.73						1.11	19.14	21.04	
3	1	152.35	127.15	25.2	98.13	1.3	19.81	25.68	134.35	111.55	22.8	98.13	1.14	20.66	23.23	135.85	93.55	42.3	0.96	45.45	43.18					
	2	156.3	115.65	40.65	98.13	1.18	35.79	41.42	139.15	110.8	28.35	98.13	1.13	25.85	28.89	136.15	98.4	37.75	1	38.62	38.37					
	3	159.35	118.95	40.4	98.13	1.22	34.15	41.17	140.35	111.3	29.05	98.13	1.14	26.05	29.61	136.85	104.45	32.4	1.07	31.27	33.05					
	4	146.15	113.55	32.6	98.13	1.16	28.8	33.22	146.45	118.4	28.05	98.13	1.21	23.62	28.59	140.65	112.8	27.85	1.15	24.92	28.27					
	5	143.05	57.45	40.95	98.13	1.04	40.1	41.73	144.7	115.45	29.25	98.13	1.18	25.52	29.81	140.2	114.7	25.5	1.17	22.12	26.02					
Average							1.18	31.73	36.64						1.16	24.34	28.03						1.07	32.48	33.78	
Station average							98.13	1.17	28.20	33.0						1.1	27.96	30.42						1.09	24.48	26.13
Scheme Average																							1.12	26.88	29.85	

Note:-w_t–weight of fresh sample, w_s–dry weight of soil, w_w–weight of moisture, v_{cs}–volume of core sampler, ρ_b–bulk density, θ–volumetric moisture content

Appendix Table 3. Dimensions of structures and conveyance efficiency of Ketar scheme

[illegible]

Appendix Table 4. Measuring Velocity of water flow using current meter

Measured structure	Reading point	Real Reading						Average Reading						Ave, vel(m/s)	H _L (m)	H _C (m)	H _R (m)	H _{ave} (m)	area (m ²)	Q (m ³ /s)
		RPM			m/s			RPM			m/s									
		L	C	R	L	C	R	L	C	R	L	C	R							
Diversion weir	60%H	4.79	5.23	4.77	2.9	1.25	1.28	4.54	5.26	4.54	1.22	1.41	1.18	1.27	0.51	0.55	0.53	53	0.47	
K –1 main canal	60%H	0.81	1.92	2.04	0.23	0.52	0.55	0.84	2.00	1.89	0.23	0.54	0.51	0.43	0.54	0.88	0.78	0.73	0.84	0.535
K-1 Secondary canal	60%H	1.36	0.86	0.98	0.37	0.19	0.98	0.27	2.44	2.53	0.91	0.65	0.69	0.75					0.33	
K-2Tertiary canal	60%H	0.79	0.31	0.68	0.22	0.09	0.18	0.80	0.36	0.69	0.22	0.10	0.19	0.17	0.6	0.6	0.55		0.23	0.039
Ketar-3 secondary canal	60%H	1.04	1.30	1.12	0.28	0.35	0.31	1.27	1.34	1.08	0.34	0.36	0.31	0.34	0.2	0.21	0.2		0.13	0.044

Appendix Table 5. Soil pH, EC, OMC and texture determination of Ketar irrigation scheme

Station	Sample No	p ^H	EC (mmhos/cm at 25°C)		OC (%)	**OMC	Soil texture			Class
							Sand (%)	Silt (%)	Clay (%)	
Ketar -1	1	6.07	0.48	2.27	3.91	36	24	40		Clay
	2	5.77	0.46	2.19	3.77	37	26	37		Clay loam
	3	5.59	0.51	2.35	4.05	44	27	39		Clay loam
	4	6.25	0.44	2.57	4.43	39	22	39		Clay loam
	5	6.16	0.46	2.4	4.14	34	25	41		Clay
	6	6.1	0.54	2.33	4.02	32	30	38		Clay loam
	7	5.59	0.46	2.3	3.96	31	26	43		Clay
	8	5.65	0.53	2.19	3.77	35	27	38		Clay loam
	9	5.77	0.49	2.21	3.81	35	27	46		Clay
Average		5.88	0.49	2.31	3.98	36	26	40		Clay loam
Ketar -2	1	5.47	0.1	1.97	3.4	30	32	38		Clay loam
	2	5.34	0.24	2.04	3.52	26	36	38		Clay loam
	3	6.03	0.21	2.19	3.77	25	37	38		Clay loam
	4	5.39	0.32	1.98	3.41	34	24	42		Clay
	5	5.29	0.12	1.94	3.34	29	35	36		Clay loam
	6	5.57	0.11	2.15	3.71	30	36	34		Clay loam
	7	5.34	0.13	2.23	3.84	32	35	33		Clay loam
	8	5.51	0.11	2.13	3.67	36	30	34		Clay
	9	5.47	0.14	2.09	3.6	34	22	44		Clay
Average		5.49	0.16	2.08	3.58	31	32	37		Clay
Ketar -3	1	5.26	0.39	1.56	2.69	38	30	32		Clay loam
	2	5.13	0.4	1.59	2.74	37	33	30		Clay loam
	3	5.33	0.41	1.53	2.64	36	29	35		Clay loam
	4	5.23	0.38	1.61	2.77	39	27	34		Clay loam
	5	5.44	0.37	1.52	2.62	35	30	35		Clay loam
	6	5.23	0.39	1.53	2.64	33	33	34		Clay loam
	7	5.54	0.36	1.7	2.93	32	34	34		Clay loam
	8	5.12	0.38	1.73	2.98	35	30	35		Clay loam
	9	5.54	0.37	1.67	2.88	34	27	39		Clay loam
Average		5.31	0.38	1.60	2.77	36	30	34		Clay loam
Scheme Average		5.56	0.34	2.00	3.44	34	29	37		Clay loam

Appendix Table 6. Infiltration rate computation of Ketar scheme

Station						ketar-2				ketar -3			
Time interval (min)	Cumulative Time (min)	Infiltration Depth (cm)	Cumulative Depth(cm)	Infiltration Rate (cm/min)	Infiltration Rate (mm/hr)	Infiltration Depth (cm)	Cumulative Depth(cm)	Infiltration Rate (cm/min)	Infiltration Rate (mm/hr)	Infiltration Depth(cm)	Cumulative Depth(cm)	Infiltration Rate (cm/min)	Infiltration Rate (mm/hr)
0	0	0	0	0	0	0	0		0	0	0		0
5	5	7	7	1.4	840	2.5	2.5	0.5	300	4.5	4.5	0.9	540
5	10	6.8	13.8	1.36	816	4	6.5	0.8	480	5	9.5	1	600
5	15	6.5	20.3	1.3	780	5	11.5	1	600	5.7	15.2	1.14	684
10	25	10.1	30.4	1.01	606	7	18.5	0.7	420	5.4	20.6	0.54	324
10	20	8.9	39.3	0.89	534	4	22.5	0.4	240	3.1	23.7	0.31	186
10	30	8.3	47.6	0.83	498	3	25.5	0.3	180	4.2	27.9	0.42	252
10	40	8	55.6	0.8	480	2	27.5	0.2	120	2.5	30.4	0.25	150
10	50	7.2	62.8	0.72	432	1.9	29.4	0.19	114	2.2	32.6	0.22	132
10	60	6.3	69.1	0.63	378	1.5	30.9	0.15	90	2	34.6	0.2	120
10	70	5	74.1	0.5	300	1.1	32	0.11	66	1.8	36.4	0.18	108
10	80	3.3	77.4	0.33	198	0.7	32.7	0.07	42	1.6	38	0.16	96
10	90	2.4	79.8	0.24	144	0.5	33.2	0.05	30	1.3	39.3	0.13	78
10	100	1.7	81.5	0.17	102	0.3	33.5	0.03	18	1.1	40.4	0.11	66
10	110	1.1	82.6	0.11	66	0.3	33.8	0.03	18	0.7	41.1	0.07	42
20	130	0.6	83.2	0.03	18	0.3	34.1	0.015	9	0.4	41.5	0.02	12
20	150	0.5	83.7	0.025	15	0.2	34.3	0.01	6	0.4	41.9	0.02	12
40	190	0.5	84.2	0.0125	7.5	0.2	34.5	0.005	3	0.4	42.3	0.01	6

Appendix Table 7. Computation of water application efficiency of Ketar scheme

Station Plot No		Ketar-1		Ketar-2		Ketar-3	
	Crop development stage	Water stored in Root zone (m ³)	Water Delivered to farm (m ³)	Water stored in Root zone(m ³)	Water Delivered to farm (m ³)	Water stored in Root zone(m ³)	Water Delivered to farm (m ³)
1	Initial	93.41	243.4	116.41	134.73	116.38	113.97
	Development	94.45	298.72	101.79	124.36	117.21	139.87
	Mid-season	99.45	376.16	82.12	165.77	86.1	165.77
	Late	100.17	188.08	77.91	98.43	73.65	98.43
Total		387.48	843.56	378.23	523.29	393.35	518.04
Plot E _a (%)		387.48	45.93		72.28		75.93
2	Initial	115.43	153.66	80.37	133.87	81.72	118.34
	Development	132.09	188.58	122.24	164.3	36.6	144.91
	Mid-season	145.55	237.47	169.13	182.55	61.08	144.91
	Late	129.2	118.74	121.31	127.79	93.41	106.27
Total		522.27	698.45	493.05	608.512	272.81	514.43
Plot E _a (%)			74.78		81.03		53.03
3	Initial	93.16	202.85	87.49	150.2	62.33	139.22
	Development	143.22	248.95	44.75	133.51	103.71	163.43
	Mid-season	110.84	313.49	62.57	144.64	110.87	196.72
	Late	121.66	156.75	45.63	127.95	77.16	118.03
Total		468.88	922.04	240.44	556.3	354.07	617.4
Plot E _a (%)			50.85		43.22		57.35
Average Station E _a (%)			57.19		65.51		62.10
Average Scheme E _a (%)							61.60

Appendix Table 8.Computation of application uniformity efficiency of Ketar irrigation scheme

Station		Ketar-1				Ketar-2				Ketar-3			
Plot No													
Development Stage													
		Wbi	Wai	Wai-Wbi	Decending order	Wbi	Wai	Wai-Wbi	Decending order	Wbi	Wai	Wai-Wbi	Decending order
1	Initial	24.54	34.40	9.86	10.27	23.21	34.54	11.33	11.33	18.59	26.1	7.51	10.09
	Development	29.25	34.40	5.15	10.24	28.54	34.54	6.00	10.81	21.47	26.1	4.63	9.89
	Mid	30.11	34.40	4.29	9.86	31.12	34.54	3.42	10.4	24.76	26.1	1.34	9.78
	Late	27.09	34.40	7.31	8.94	29.01	34.54	5.53	9.93	17.81	26.1	8.29	9.62
	Initial	26.45	33.40	6.95	7.63	21.72	30.94	9.22	9.22	19.11	29.00	9.89	8.69
2	Development	28.42	33.40	4.98	7.31	20.54	30.94	10.4	7.91	20.31	29.00	8.69	8.29
	Mid	30.29	33.40	3.11	6.95	20.12	30.93	10.81	7.44	22.93	29.00	6.07	8.13
	Late	29.20	33.40	4.2	5.15	21.01	30.94	9.93	6.16	18.91	29.00	10.09	7.51
	Initial	22.76	33.00	10.24	4.98	20.45	28.36	7.91	6	19.92	29.70	9.78	6.07
	Development	24.06	33.00	8.94	4.29	22.2	28.36	6.16	5.53	21.57	29.70	8.13	5.97
3	Mid	25.37	33.00	7.63	4.2	23.15	28.36	5.21	5.21	23.73	29.70	5.97	4.63
	Late	22.73	33.00	10.27	3.11	20.92	28.36	7.44	3.42	20.08	29.70	9.62	1.34
Mean of soil moisture from irrigation event of Station					6.91	7.78				7.50			
mean of soil moisture of least quarter from irrigation event					4.15	5.04				4.50			
Application Uniformity of Station (%)					59.98	64.78				60.03			
Average Application uniformity of Ketar (%)										61.60			

Appendix Table 9.Computation water storage efficiency of Ketar scheme

Station	Ketar-1						Ketar-2					Ketar-3					
Plot No																	
Crop Development stage																	
	W_{bi}	W_{fc}	W_{ai}	$W_{fc}-W_{bi}$	$W_{ai}-W_{bi}$	W_{bi}	W_{fc}	W_{ai}	$W_{fc}-W_{bi}$	$W_{ai}-W_{bi}$		W_{bi}	W_{fc}	W_{ai}	$W_{fc}-W_{bi}$	$W_{ai}-W_{bi}$	
1	Initial	24.5	34.4	40.7	9.9	16.2	23.2	35	37.3	11.3	14.1	18.6	26	31.1	7.5	12.5	
	Development	29.3	34.4	43.5	5.1	14.2	28.5	35	40.9	6	12.4	21.5	26	34.1	4.6	12.6	
	Mid Season	30.1	34.4	40.5	4.3	10.4	31.1	35	41.1	3.4	10	24.8	26	34	1.3	9.2	
	Late	27.1	34.4	41.1	7.3	14	29	35	38.4	5.5	9.4	17.8	26	25.7	8.3	7.9	
	Total	26.5				51.9	26.2				45.9	21.7				42.2	
Storage Efficiency of plot (%)						195.8					175.2					194.5	
2	Initial	26.5	33.4	38.2	6.9	11.7	21.7	31	31.3	9.2	9.6	19.1	29	28.7	9.9	9.6	
	Development	28.4	33.4	40.3	5	11.9	20.5	31	35.1	10.4	14.6	20.3	29	24.6	8.7	4.3	
	Mid Season	30.3	33.4	42.8	3.1	12.5	20.1	31	40.3	10.8	20.2	22.9	29	30.1	6.1	7.2	
	Late	29.2	33.4	41.8	4.2	12.6	21	31	35.5	9.9	14.5	18.9	29	29.9	10.1	11	
	Total	19.2				48.7	40.3				58.9	34.8				32.1	
Storage Efficiency of plot (%)						253.6					146.15					92.2	
3	Initial	22.8	33	34.3	10.2	11.5	20.5	28	30.4	7.9	9.9	19.9	30	27.2	9.8	7.3	
	Development	24.1	33	41.8	8.9	17.7	22.2	28	27.3	6.2	5.1	21.6	30	33.6	8.1	12	
	Mid Season	25.4	33	39.1	7.6	13.7	23.2	28	30.3	5.2	7.1	23.7	30	36.6	6	12.9	
	Late	22.7	33	37.8	10.3	15.1	20.9	28	26.1	7.5	5.2	20.1	30	29	9.6	8.9	
	Total	37				58.1	26.7				27.4	33.5				41.1	
Storage Efficiency of plot (%)						157.0					102.5					122.7	
Average storage efficiency of station %)						202.2					141.3					136.5	
Average Storage efficiency of Scheme (%)												160.0					

Appendix Table 10. Soil moisture deficit and depletion fraction (DF) of Ketar irrigation scheme

Station			Ketar-1						Ketar-2						Ketar-3											
			Wbi (%)	Wfc (%)	Asi	Di (mm)	SMD(mm)	TAW (mm)	DF (%)	Wbi (%)	Wfc (%)	Asi	D _i (mm)	SMD (mm)	TAW (mm)	DF (%)	Wbi (%)	Wfc (%)	A _{si}	Di	SMD (mm)	TAW (mm)	DF (%)			
1	Plot	Stage																								
		Initial	26.4	34.4	1.1	600	50.4	74.2	67.9	23.2	34.5	1.08	600	73.4	84	87	18.6	26.1	1.3	600	58.4	80.42	72.57			
		Development	28.4	34.4	1.1	600	37.8	74.2	51	28.5	34.5	1.08	600	38.9	84	46	21.5	26.1	1.3	600	36.1	80.42	44.85			
		Mid Season	30.3	34.4	1.1	600	25.9	74.2	35	31.1	34.5	1.08	600	22.2	84	26	24.8	26.1	1.3	600	10.6	80.42	13.19			
		Late	29.2	34.4	1.1	600	32.9	74.2	44.3	29	34.5	1.1	600	35.8	84	43	17.8	26.1	1.3	600	64.4	80.42	80.08			
		Average						147	297						170	336						169	321.7			
		Plot DF (%)								49.5								51								52.67
	2		Initial	23.4	33.4	1.1	600	66.5	76.8	86.6	21.7	30.9	1.2	600	65.8	78	84	19.1	29	1.2	600	71.8	80.51	89.18		
			Development	23.4	33.4	1.1	600	66.7	76.8	86.8	20.5	30.9	1.2	600	74.3	78	95	20.3	29	1.2	600	63.1	80.51	78.36		
			Mid Season	25.2	33.4	1.1	600	54.8	76.8	71.4	20.1	30.9	1.2	600	77.3	78	99	22.9	29	1.2	600	44.1	80.51	54.74		
		Late	23.3	33.4	1.1	600	67.5	76.8	87.9	21	30.9	1.2	600	70.9	78	91	18.9	29	1.2	600	73.3	80.51	90.99			
		Total						255	307						288	312						252	322			
		Plot DF (%)								83.2								92								78.3
3			Initial	22.8	33	1.2	600	71.7	75.7	94.8	20.5	28.4	1.2	600	55.5	73		19.9	29.7	1.2	600	70.8	81.38	86.98		
			Development	24.1	33	1.2	600	62.6	75.7	82.7	22.2	28.4	1.2	600	43.2	73		21.6	29.7	1.2	600	58.8	81.38	72.26		
			Mid Season	25.37	33	1.2	600	53.4	75.7	70.6	23.2	28.4	1.2	600	36.6	73		23.7	29.7	1.2	600	43.1	81.38	52.99		
			Late	22.73	33	1.2	600	72	75.7	95.1	20.9	28.4	1.2	600	52.2	73		20.1	29.7	1.2	600	69.6	81.38	85.55		
								260	303						188	292						242	325.5			
								220.7	302.3						215.3	313.3						221.3	323.1			
		Scheme Average																					219.1	312.9		
		Plot DF(%)								85.8								64.2								74.45
		Station DF(%)								72.8								69.1								68.5
		Scheme DF(%)																					70.1			

Appendix Table 11.Computation of E_a , RR,DPF and IWUE for Ketar scheme

		Plot Area (m ²)	Water Delivered to plot (m ³)	Irrigation water applied (m ³ / m ²)	Water Stored in root zone (m ³)	Total water loss (m ³)	Volume of Runoff (m ³)	Yield From Plot (kg)	Actual Yield (kg/ m ²)	Application Efficiency (E_a) (%)	Runoff Ratio (RR) (%)	Deep Percolation Fraction (DPF) (%)	Irrigation Water Use Efficiency (kg/m ³)
Station													
Plot													
		1	2	3	4	5	6	7	8	9	10	11	12
Ketar-I	1	1250	843.56	0.67	387.48	456.08	391.1	2200	1.76	45.93	46.361	7.70	1.99
	2	1175	698.45	0.59	522.27	176.18	143.8	1550	1.32	74.78	20.585	4.64	2.22
	3	1150	922.04	0.80	468.88	453.16	344.1	2000	1.74	50.85	37.318	11.83	2.17
Average				0.69						57.19	34.75	8.06	2.13
Ketar-II	1	1275	523.29	0.41	378.23	145.06	100.4	1350	1.06	72.28	19.191	8.53	2.58
	2	1175	608.51	0.52	493.05	115.46	81.2	1720	1.46	81.03	13.343	5.63	2.83
	3	1250	556.3	0.44	240.44	315.87	241.7	1640	1.31	43.22	43.456	13.32	2.95
Average										65.51	25.33	9.16	2.79
Ketar-III	1	1200	518.04	0.43	393.35	124.69	77.7	1200	1.00	75.93	15.005	9.06	2.32
	2	1175	514.43	0.44	272.81	241.62	143.5	1080	0.92	53.03	27.886	19.08	2.10
	3	1187.5	617.4	0.52	354.07	263.33	170.6	1210	1.02	57.35	27.634	15.02	1.96
Average										62.10	23.51	14.39	2.23
Scheme average										61.60	27.86	10.54	2.13

Appendix Table 12. ANOVA Procedure for application efficiency of Ketar scheme

Source of Variation	DF	SS	MS	F Value (F-ratio)	F-tabular F _{10%} (4,2) F _{5%} (4,2)		Pr> F
Treatment	2	601.20	300.60	1.24	4.32	6.94	F-tab>F-value
Replication	2	109.02	54.51	0.22			
Error	4	970.52	242.63				
Corrected Total	8	1680.74					

Appendix Table 13. ANOVA Procedure for storage efficiency of Ketar scheme

Source	DF	Squares	Mean Square	F Value (F-ratio)	F-tabular F _{10%} (4,2) F _{5%} (4,2)		Pr> F (F-tab>F-value)
Treatment	2	5522.06	2761.03	1.57	4.32	6.94	
Replication	2	7985.62	3992.81	2.27			
Error	4	7021.96	1755.49				
Corrected Total	8	20529.63					

Appendix Table 14. ANOVA procedure for runoff ratio of Ketar scheme

Source	DF	Sum of squares	Mean Square	F Value (F-ratio)	F-tabular F _{10%} (4,2) F _{5%} (4,2)		Pr> F (F-tab>F-value)
Treatment	2	223.72	111.86	0.75	4.32	6.94	0.5282
Replication	2	362.98	181.49	1.22			0.3858
Error	4	595.03	148.76				
Corrected Total	8	1181.73					

Appendix Table 15. ANOVA Procedure for DPF of Ketar irrigation scheme

Source	DF	Squares	Mean Square	F Value (F-ratio)	F-tabular F _{10%} (4,2) F _{5%} (4,2)		Pr> F (F-tab>F-value)
Treatment	2	39.72	19.86	1.16	4.32	6.94	0.4008
Replication	2	69.50	34.75	2.03			0.2465
Error	4	68.54	17.13				
Corrected Total	8						

Appendix Table 16. ANOVA Procedure IWUE of Ketar irrigation scheme

Source of Variation	DF	Sum of Squares	Mean Square	F Value (F-ratio)	F-tabular F _{10%} (4,2) F _{5%} (4,2)		Pr> F (F-tab>F-value)
Treatment	2	0.86	0.43	10.68	4.32**	6.94*	0.0249
Replication	2	0.01	0.01	0.15			0.8692
Error	4	0.16	0.04				
Corrected Total	8	1.03					
CV	7.10						

Appendix Table 17.Procedures Applied for Redesign of Scheme

1. Lined Trapezoidal Canal Design Procedures

$Q = 0.518 \text{ m}^3/\text{s}$, $V = 1.5 \text{ m/s}$, $n = 0.017$, $S = 0.0055$, side slope 1.5:1 (H:V) $\Rightarrow z = 1.5$

$$\text{Manning Equation } Q = \frac{1}{n} A R^{\frac{2}{3}} S_o^{\frac{1}{2}}$$

Step 1. Canal cross sectional area computation

$$Q = A \times V = A = \frac{Q}{V} = \frac{0.518}{1.5} = 0.345 \text{ m}^2$$

Step 2. Hydraulic radius (R) computation

$$V = \frac{1}{n} R^{\frac{2}{3}} S_o^{\frac{1}{2}} = R = \left(\frac{V n}{\sqrt{S_o}} \right)^{\frac{3}{2}} = \left(\frac{1.5 \times 0.017}{\sqrt{0.0055}} \right)^{\frac{3}{2}} = 0.202 \text{ m}$$

Step 3. Wetted perimeter (W_p) computation

$$R = \frac{A}{W_p} \Rightarrow W_p = \frac{A}{R} = \frac{0.345}{0.202} = 1.713 \text{ m}$$

Step 4. Computation of flow depth (d) and Canal bed (b) based on cross section area and wetted perimeter of trapezoid.

$$W_p = b + 2d\sqrt{z^2 + 1} \Rightarrow 1.713 = b + 2d\sqrt{1.5^2 + 1} = 1.713 = b + 3.61d$$

$$b = 1.713 - 3.61d \text{ --- (1)}$$

$$A = bd + zd^2 \Rightarrow 0.345 = bd + zd^2 \Rightarrow 0.345 = bd + 1.5d^2 \text{ --- (2)}$$

$$\text{Inserting (1) into (2)} \Rightarrow 0.345 = (1.713 - 3.61d)d + 1.5d^2 =$$

$$0.345 = 1.713d - 3.61d^2 + 1.5d^2$$

$$0.345 = 1.713d - 2.11d^2$$

$$2.11d^2 - 1.713d + 0.345 = 0$$

$$X = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Using Quadratic Equation

$$d = \frac{-(-1.713) \pm \sqrt{(-1.713)^2 - 4 \times 2.11 \times 0.345}}{2 \times 2.11}$$

$$\Rightarrow d = 0.37 \text{ m or } 0.441 \text{ for economic design small } d = 0.37 \text{ m was selected}$$

Step 5. Freeboard (Fb) computation = 10% d = 0.1 x 0.37 m = 0.037 m

Step 6. Computation of overall depth (D)

$$D = d + F_b = 0.37 + 0.037 = 0.407m$$

Step 7. Computation of bed width (b)

$$\Rightarrow b = 1.713 - 3.61d = 1.713 - 3.61 \times 0.37 = 0.38m$$

Step 8. Computation of water level width (t)

$$t = b + 2dz = 0.38 + 2 \times 0.37 \times 1.5 = 1.12m$$

Step 9. Computation of top canal width (T)

$$T = b + 2Dz = 0.38 + 2 \times 0.407 \times 1.5 = 1.601m$$

Note : Q=Discharge in canal (m³/s)

V= flow velocity in canal (m/s)

n=Manning roughness coefficient

z=side slope of canal

S_o=longitudinal slope of canal

A=cross sectional area of canal

W_p=Wetted perimeter

R=Hydraulic radius

2. Reservoir Design Procedures

$$B_1 = B_2 + 6h \quad A_1 = (B_1)^2 = (B_2 + 6h)^2 \quad A_2 = (B_2)^2$$

$$V = \frac{h}{3} (A_1 + A_2 + \sqrt{A_1 * A_2})$$

$$V = \frac{h}{3} \left[(B_1)^2 + (B_2)^2 + \sqrt{(B_1^2 * B_2^2)} \right]$$

$$V = \frac{h}{3} \left[(B_1)^2 + (B_2)^2 + B_1 * B_2 \right]$$

$$V = \frac{h}{3} [B_2^2 + 12 h B_2 + 36 h^2 + (B_2)^2 + (B_2 + 6h) * B_2]$$

Note B_1 =Reservoir top width

B_2 =Reservoir bottom width

h =water depth in the reservoir

V =volume of reservoir

$$V = \frac{h}{3} [B_2^2 + 12 h B_2 + 36 h^2 + (B_2)^2 + (B_2^2 + 6h B_2)]$$

$$V = \frac{h}{3} [3B_2^2 + 18 h B_2 + 36 h^2]$$

4m was selected for h as assumption

$$16891.2 = \frac{4}{3} [3B_2^2 + 18 \times 4 B_2 + 36 \times 4^2]$$

$$4222.8 = B_2^2 + 24 B_2 + 192$$

$$B_2^2 + 24 B_2 - 4030.6 = 0$$

Using Quadratic Equation $X = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

$$B_2 = \frac{-24 \pm \sqrt{24^2 - 4(1)(-4030.6)}}{2 \times 1}$$

$$B_2 = \frac{-24 \pm 129.22}{2} = B_2 = 52.61m. \text{ or } -76.61m$$

$B_2 = 58.61m$. positive and small value was selected for design

to be on the safe side and to be economic. Therefore $B_2 = 52.61m$

$$B_1 = B_2 + 6h = 52.61m + 6 \times 4 = 76.61m$$

Free board and evaporation was taken as 10%h, total reservoir Height (H) was 0.4m.

$$T = B_1 + 2Hz = 76.61 + 2 \times 4.4 \times 3 = 103.01m$$

$$W = \frac{B_1 - B_2}{2} = \frac{76.61 - 52.61}{2} = 12m$$

$$A_p = \sqrt{H^2 + W^2} = \sqrt{4.4^2 + 12^2} = 12.78m$$

$$S = \sqrt{A_p^2 + W^2} = \sqrt{12.78^2 + 12^2} = 17.53m$$

7.2. AppendixFigures



Appendix Figure 1. Discharge Measurement by Current Meter at Diversion head and Different Segments



a. Chute to K-III



b. ReservoirKetar –III Night storage

Appendix Figure 2.Structures of Ketar Irrigation Scheme



a. Parshall Flume Leveling

b. Flow Through Inlet

c. Flow through outlet

Appendix Figure 3. Discharge Measurement Using Parshall Flume at Field Channel



Appendix Figure 4.. Infiltration Measurement of Selected Plots



Appendix Figure 5. Soil Sample Collection for Laboratory Analysis



Appendix Figure 6. Study Area Supervision