Water use efficiency of smallholder irrigation in the Ethiopian Central Rift Valley

The case of Haleku Melka-Tesso irrigation project

Internship report by Beshir Keddi Lencha

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Irrigation and Water Engineering Group

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The case of Haleku Melka-Tesso Irrigation project

An internship in Irrigation and Water Engineering submitted in partial fulfillment of the degree of Master of Science in International Land and Water Management at Wageningen University, the Netherlands

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Acronyms

A1, A2, C3: plot 1 of block A, plot 2 of block A, etc.

CRV: Central Rift Valley

CWR: Crop water requirements

DA: Development agent

Ea: Application efficiency

Ec: Conveyance efficiency

ECe: Electric conductivity

eFC, eWP: Moisture at field capacity, permanent wilting point

Ei: Irrigation efficiency

Etc: Crop evapotranspiration

GPS: Global positioning system

Ha: Hectare

HOA-REN: Horn of Africa Regional Environmental Network

IR: Irrigation requirements

KWH: Kilo-Watt-hours

NGO: Non governmental organization

PWP: Permanent wilting point

Q: Discharge

RAW: Readily available water

RCWD: Rift valley Children and Women Development

RIS: relative irrigation supply

RWS: Relative water supply

SOM: soil organic matter content

SPAW: Soil Plant Air Water

TAW: Total available water in the soil

USDA (USDA SCS): United Stats Department of Agriculture (Soil Conservation Service)

WUA: Water user association

WUE: Water use efficiency

Summary

The Central Rift Valley (CRV) is a semi-arid area in Oromia region, some 150 km south of Addis Ababa. The local population in the CRV heavily depends on rain fed agriculture with low productivity and economic returns. Irrigated agriculture is one of the alternatives to improve the livelihoods of the local population. Though water resources in the CRV offer ample opportunities for irrigation the recent increase in irrigation water abstraction has already resulted in their over-exploitation. This is a threat for the environment and the ecosystem.

The aim of this research (part of an internship) was to assess the water use efficiency of a smallholder irrigation project, to identify causes of current performance of the project and to provide recommendations to improve its performance. The Haleku Melka-Tesso irrigation project was selected for this study as it was supposedly a better performing project compared to other smallholder irrigation projects supported by the government. Haleku is one of the smallholder irrigation projects established with financial and technical assistance from a local NGO, the Rift Valley Children and Women Development. The project abstracts water from the Bulbula river that originates from Lake Ziway.

Nine farmers' fields were selected to assess and compare irrigation water use efficiencies. The average size of the selected fields was 0.25 ha. The soil texture of the plots was sandy loam with a pH of about 8.4, and soil organic matter content varying between 1.3 and 1.9% in the top soil layer. The selected fields were cultivated with onion, tomato and pepper which are among the major irrigated vegetable crops in the CRV. The data collection was carried out from May 2008 to July 2008. The data that were collected during the study period included the discharge pumped, discharge received at plot level, amount of irrigation water applied (mm) per irrigation event, energy used for pumping, area irrigated per day, total number of irrigation events. Crop water requirements, irrigation water requirement and irrigation scheduling for optimum conditions were estimated using the CropWat model. The soil texture and other physical parameters and the amount of available moisture prior to an irrigation event and after an irrigation event was done at the local soil lab in Ziway.

Farmers apply irrigation water independent of crop water requirements. The average interval for applying irrigation water for all crops is 3 to 5 days. If there is rain or if rain is anticipated, the irrigation interval may be longer. Also in the study period the intervals were longer due to electricity cuts.

In the Haleku irrigation project every litre of irrigation water has a cost for electricity used to pump the water. The farmer's perceive that water is not free, but water is paid according the irrigated area and not according the amount of water applied (water diverted to a given field). Application of excess water beyond field capacity is common. Farmers are supposed to take water from a secondary canal that passes along their field. But some of such secondary canals do not convey water easily as there is a head problem. So, farmers stick to a secondary canal far from their plot, which forces them to convey water in a tertiary canal for longer distances.
Losses are high when water is conveyed longer distances in tertiary canals as compared to those fields that take water from secondary canals that pass along their plots. As fields using tertiary canals are far from the source (point of diversion or inlet), they divert a higher discharge as compared to fields receiving water directly from a secondary canal. The size of

the tertiary canals is a bit smaller to convey the discharge from the secondary canal. Losses due to seepage and overtopping are common. For all canals that convey small amounts of discharge, losses due to overtopping (breaching) of the canal are low. Measurements carried out on the tertiary canals that convey water to sample plots showed that there can be losses of more than 40%. Major reason for the higher loss of the tertiary canals is their size as most of the loss is due to overtopping.

The conveyance efficiency in the main canal ranges from 91 to 96 % and 67 to 85% for the lined part and unlined part, respectively. For the secondary canals it ranges from 66 to 89 % and the tertiary canals from 40 to 95%. The loss per meter length of the canals (main, secondary and tertiary) varies between 0.01 to 0.32 l/s. The higher losses correspond to the canals that convey a discharge that is greater than their capacity. The conveyance efficiency of the sample plots, taking the contribution of the canals at all hydraulic levels varies between 37 to 65%.

Estimated irrigation water requirements for onion, tomato and pepper were 394, 367 and 455 mm, respectively. The assessment showed that irrigation water is supplied in onions varying between 327 and 966 mm. For tomato, the actual irrigation water supply varied between 595 and 913 mm. For pepper, it was about 720 mm per season. The total amount of irrigation water applied per hectare/season for onion, tomato and pepper varied between 3270 and 9660 m^3/ha/season.

The irrigation efficiency of the nine plots varies between 18 and 55% which corresponds with the irrigation efficiency of smallholder projects reported in other studies. The RWS and RIS are in the order of 1.21 to 2.75 (RIS: 1.11 to 2.82) for onion, for tomato 1.5 to 2.38 (RIS: 1.57 and 2.9), and for pepper 1.55(RIS: 1.58).

The amount of water pumped per day for a typical irrigated area of 0.9 to 6.5 ha is about 878 and 8050 m^3, respectively. There was no shortage of water to supply crops even during the dry periods. The records of the WUA showed that onion yields of sample plots varied between 7,200 to 24,300 kg/ha. Tomato yields varied between 20,000 to 31,100 kg/ha while pepper yields were on average 2,800 kg/ha. The gross revenue (yield times price) from onion in the study period was in the range of 5764 to 19,436 Birr per 0.25 ha, for tomato it was about 3500 to 5450 Birr per 0.25 ha, and for pepper it was 3500 Birr per 0.25 ha.

The water use efficiency of Haleku is low and there is a room for improvements. The conveyances losses could be reduced by lining of the canals (at least the entire main canal) and increasing the capacity of the canal, especially in the downstream part. Simple irrigation water division structures and devices could be installed in canals to control and measure water supply. Training on irrigation and water management is also important. The design of a fair payment system based on the actual amount of water supplied could encourage farmers to use irrigation water more efficiently.

1. Introduction

1.1 Background

The slogan ‘more crop per drop’ calls for improving the efficiency of water use to meet future global food demand as well as reducing the excessive wastage of water (Lankford, 2006). Improving water use efficiency may minimize adverse local effects such as water logging, effects of salinity, contribute to maintaining environmental (river) flows and may increase economic returns (Marsden Jacob Associates, 2003). Assessing water use efficiency of irrigation schemes and implementation of strategies to improve water use efficiency is one of the important ways to enhance water savings and safeguarding the environment (Wigginton and Raine, 2000).

However, water-use efficiency (WUE) is an ambiguous and scale-related concept that has been used for many years in relation to irrigated agriculture (Lefebvre et al., 2005). (Machibya et al. 2004) defined WUE as the ratio between water used for an intended purpose (ETc, leaching) and the total amount of water supplied. Irrigation efficiency is a special case of WUE (Machibya et al., 2004) and is defined as the ratio between the amount of water consumed by the crop (actual Etc) and the amount of water supplied through irrigation. In contrast, productivity of water is usually a measure of the economic, livelihood or biophysical outputs derived from the use of a unit of water for example, jobs per m^3, $/$m^3$, total biomass (kg/$m^3$), etc.

Unlike productivity (which has units), efficiency is expressed as a fraction or percentage. Other related efficiencies are: Scheme irrigation efficiency, i.e. that part of the water pumped or diverted through the scheme inlet which is used effectively by the plants (Brouwer et al., 1989). It includes conveyance efficiency (ec) representing the efficiency of water transport in canals and field application efficiency (ea) represents the efficiency of water application in the field.

Information on the performance of existing irrigation practices will help to identify constraints and options for improved practices in irrigation extension programs. Improvement of water management and water use efficiency requires information on crop water consumption and current water management.

The Ethiopian Central Rift Valley (CRV) is closed basin covering an area of 10000 km^2, which encompasses a chain of three large lakes namely, Ziway, Langano and Abyata, is an environmentally vulnerable area (Jansen et al., 2007).

Rainfall in the area (catchment) has been relatively constant over the last ten years but irregularity of rainfall distribution hampers rain-fed agriculture and results in widespread poverty. To reduce poverty, irrigated agriculture (small-scale and large scale) has been promoted by the government and NGO’s resulting in a rapid expansion of the irrigated area. Total annual water abstraction by of irrigated agriculture has been estimated to be in the range of 150 - 200 million m^3 for an area between 7500 and 10000 ha.

Currently, there are interventions by the government and NGO’s (local and international) and research activities such as the project “Ecosystems for water, food and economic development in the Ethiopian CRV” supported by the Netherlands government aimed supporting the policy debate on the sustainable use and management of water and land resources in the CRV.

This research will help to identify areas of poor management with respect to irrigation water and solutions to improve water use efficiencies. Possibilities of saving water and minimizing operational cost associated with fuel cost for pumps will be assessed.

1.2 Problem statement

As a result of the recent expansion of (mainly) smallholder irrigation, the average level of Lake Ziway has decreased by approximately 0.5 m since 2002. As a consequence the discharge of river Bulbula has decreased tremendously resulting in a reduction in size of Lake Abyata with more than 40% of its size in 1999 (Jansen et al., 2007). Poor water management in smallholder schemes is also associated with poor agronomic and economic performance of such schemes, i.e. more efficient use of water could contribute to improved economic returns in irrigated systems (Mengistu, 2008).

One of the knowledge gaps in the analysis of Jansen et al. (2007) is the efficiency of irrigation water in smallholder schemes. Accurate data on water use by smallholder farmers at scheme level is not monitored and not known which hampers the assessment of water use efficiency and water productivity of these schemes. In order to improve our knowledge about the hydrological system dedicated assessments need to be carried out.

As most of the irrigation schemes in this area depend on pumps to abstract water from rivers (Bulbula) or Lake Ziway, the abstraction costs are high. Increasing the efficiency of such systems may reduce the cost of pumping (less working hours) and fuel costs.

Identification of the water use efficiency in irrigation schemes and improved practices may contribute to protection of the catchment (environment) as well as to improve the livelihood of the communities depending on irrigated agriculture. The main aim of this research is to better estimate current irrigation water use efficiencies at plot and scheme level and to identify options for improved efficiencies.

1.3 Objectives

- *To assess irrigation efficiency (conveyance and application) of irrigation schemes.*
- *To assess the status of water delivery in irrigation schemes.*
- *To assess the total (irrigation) water abstracted (used) per growing season.*
- *To find options for improving efficiency and minimizing the operational costs (fuel cost) of irrigation schemes.*

1.4 Research questions

The purpose of this research is to study and identify (irrigation) water use efficiencies in a selected scheme. The specific research questions are:

- How irrigation water is delivered (distributed) within the irrigation scheme?
- What is the irrigation interval practiced in the irrigation scheme?
- What is the conveyance efficiency of the irrigation scheme?
- What is application efficiency of the irrigation scheme?
- What is the irrigation efficiency of the irrigation scheme?
- What is the relative water (irrigation) supply of the scheme?
- What is the total volume of water abstracted for one growing season?
- What measures are required to improve the water (irrigation) use efficiency of smallholder irrigation schemes?

2. Materials and methods

2.1 Descriptions of the study area

Establishment: The Haleku Melka-Tesso irrigation project was established in 2001 with a total command area of 36 ha with support of a local NGO Rift valley Children and Women Development (RCWD). Prior to the development of the irrigation project, farmers in the area relied on the production of rain fed crops and livestock. The agricultural production was not satisfactory due to low rainfall. The farmers were forced to move and work in the neighbouring towns and state farms as daily labourers and most of them depended on relief programs..

History and organizational setup of the project: Originally the area proposed for irrigation was about 36 ha while more land (about 5 ha) was added later. The farmers in the irrigation project received support from RCWD through financial and technical support to the WUA. The management of the WUA is in the hand of the members while the development agent (DA) assigned and paid by RCWD gives advice and technical support.

During the establishment of the project, there were about 65 members registered. Currently there are 75 members (60 male and 15 female) and the WUA anticipate the number of members to increase in the future as they have a plan to increase the command area with help of RCWD. There is more land within the vicinity of the project that has been proposed to be included within the project. Previously, even after the establishment of the WUA, the management of the project was done by RCWD. Even after the WUA was legalized in 2001, the management was carried out by the RCWD till 2007/08 when the farmers(members and the different assigned committees) started managing the operation of the irrigation project (water management and financial issues). Still the financial issues are being done by the DA assigned by the NGO. There is a plan to transfer all financial issues to the farmers starting the coming year (2008/09).

Location and topography:
Haleku Melka-Tesso Irrigation Project is located in the CRV in the Ziway Basin, 169 km south of Addis Ababa and 9 km from Ziway town and around 4 km on the left side of Adami Tulu town. Geographically the scheme is located at latitude of 7^{o}50' North and longitude of 38^{o} 42' East in Eastern Shoa administrative region. The scheme is bounded by the Bulbula River in the east; the elevation of the project area is around 1646 meters above sea level. For the location and altitude of the sample plots, pump station ant the office see Annex I.The land is characterized by plain land of very gentle slope, which is suitable for surface irrigation.

Climate: based on the meteorological data of Ziway Research Centre, the nearest weather station, average rainfall in the project area is 602 mm mainly received from June to August followed by a distinct dry spell up to January. This is often preceded by secondary or small rainy season running from February to April. The mean daily minimum and maximum temperature in the project area is in the order of 17.1 ^{o}C and 26.9 ^{o}C, respectively. The area belongs to the semi-arid drought prone areas of the country.

2.2 The Haleku scheme

The Haleku irrigation scheme is divided into three blocks (A, B and C) with an area of 12 ha each. The area within each block is assumed to be planted within the same period. The 2nd block with a delay of about 2 to 3 weeks compared to the 1st block, and the 3rd block a similar delay as compared to the 2nd block to minimize the peak water requirement by stratifying (staggering) the planting date. Within each block all farmers have a plot of about 1/3 of their total irrigated land holding. In each block there are 6 teams (groups) consisting of 12 members that request water at the same time. Water is circulated among the 12 members before the next team within that block gets water. Irrigation used in the area is block ended furrow in which the water is blocked at the end of a furrow to avoid runoff and give more opportunity to infiltrate. No run-off was observed in the project area.

Water sources and abstraction: The irrigation project draws water from Bulbula River that gets water from Ziway Lake. The project has 2 pumps (one electric and one diesel) with a capacity of 100 l/s each to abstract irrigation water from the river. The actual average discharge of the pumps are 100 litres per second each.

2.3 Water distribution system

Irrigation water is pumped from Bulbula River and discharged to a lined canal which has a stilling basin that is used to dissipate the energy and silt down the sediments in the water. The first part of the canal is in fill that easily conveys water that is pumped from the river. Subsequently, 500 meter stone masonry made primary canal that is joined by unlined part (1 km) carries the water to secondary canals. The secondary canals having a length ranging from 300 to 450 m run along the plots of each farmer longitudinally from the main canal. Farmers directly divert water from the secondary canals that run alongside their plot to the field supply channels that delivers water to their plots. There are two pipes that take water from the main canal and deliver to canals that serve as secondary. Farmers divert the water through their preferred direction as long as it has a head and conveyed to their field. But there are places where irrigation water is conveyed via tertiary canals that take water from a distant secondary canal. Even if all plots have a secondary canal adjacent to them, farmers also made ditches by crossing the access road used to separate a block from the other to take advantage of the water in the secondary canal above. Water in the canal (main and secondary) is divided in to the respective parts (secondary/ tertiary) using straws and soil and no one knows the amount of water received and divided among a group of farmers irrigating at a time.

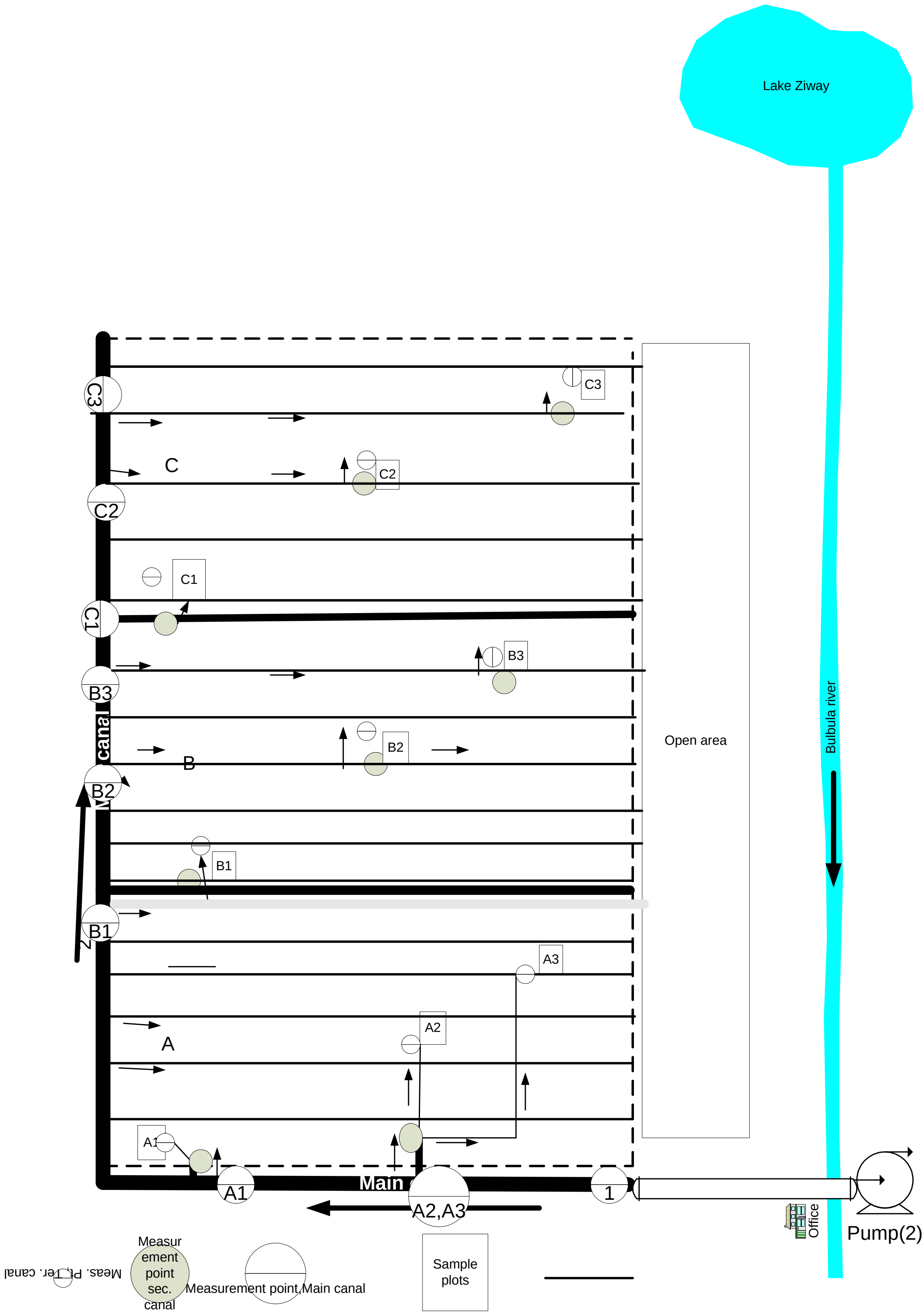

Figure 2.1 Schematic diagram of Haleku irrigation scheme.

2.4 Methodologies used

2.4.1 Primary data collection

Field observation and measurements were done to investigate the method of water application and practices related to water management in the scheme.

Discharge and application time

The discharge delivered to the scheme and the sample plots was measured frequently during each irrigation event at the point of diversion (head of the main canal) and at the point of water intake to the plots. The amount of irrigation water pumped (to the main canal) was measured using a current meter (propeller) in different parts of the main canal mostly above the diversion points to the sample plots selected from each block. A 20 cm cut-throat flume was used to measure the discharge in the secondary canal, while a 10-cm cut throat flume was used to measure discharges in the tertiary canals. For the purpose of analysis in the main canal level, two points for each sample plot (1: the point of diversion of the upstream sample plot and 2: point of diversion of the sample plot itself) was used. For example. for sample plot B2, the two points are the point of diversion of the sample plot above B1 and the point of diversion to the sample plot B2. The discharge measured at plot level was combined with the duration of the discharge (application time) to determine total water (volume) applied during each irrigation event of the sample plot during the study period (May-June). The amount of water delivered (discharge in l/s) multiplied by the application time gives the total amount of water applied to a given plot. Cross checks were carried out to identify variations in discharges applied to each plot based on crop stages or other priorities by interviewing farmers, field observations and looking on the discharge delivered to different plots at different crop stages. The plot areas owned by a farmer and irrigated during each period was measured.

Soil physical properties

The physical properties of the soil in the scheme, i.e. texture, organic matter content, ECe, salinity, pH, and soil moisture content (before and after some irrigation events of the sample plots) was measured and analyzed at the local soil laboratory located in Ziway town.

Moisture content was assessed before and after irrigation of some irrigation events during the study period using gravimetric method to determine the available soil moisture and the amount of water retained within the root zone for the crops. These were compared with the amount applied to determine the application efficiency. This was done by taking soil samples at different depths of the profiles up to the limit of the rooting depth of the crop in the scheme.

Mapping

Mapping of the entire area, the blocks (the divisions) and the sample plots within each block was done using GPS to determine the coordinates of the sample plots and other structures of the scheme.

2.4.2 Secondary data collection

The following secondary data was collected from the farmers, the development agent in the area and records of the WUA:

- Planting date of the crops
- Meteorological data for calculating reference ET and calculating the crop water(irrigation) requirements.
- Number of irrigation events in the previous months and the whole irrigation season.
- Amount of energy used (KWH) per day for the whole irrigation season.
- Hours of pumping for different blocks and crops at different stages.

2.5 Data analysis

- ***Textural classes*** and other physical soil properties from each sample plot was analyzed (eFC, eWP) in the soil lab at Ziway.

- **Moisture holding capacity of the soil** in the area was determined using SPAW software by using the above measured soil parameters as an input. The results found from SPAW were used to estimate the moisture holding capacity of the soil in the project area. TAW and RAW were determined using SPAW software based on the physical characteristics(texture, organic matter content, salinity, compaction) of the soil in the scheme.

- ***Crop water requirements:*** The CropWat 8 model was used to estimate the reference evapotranspiarion (Penman Montheith method), crop water requirement, irrigation scheduling and irrigation water requirement of the crops grown in the area (FAO, 2008). The irrigation water requirements were determined by estimating the effective rainfall using the USDA-SCS method. Crop coefficients were taken from FAO publication. Other crop information (rooting depth, growth period) were obtained from the DA.

- ***Evapo-transpiration***: FAO (2007) was used to calculate the amount of irrigation water required for optimum production. Crop water requirements (irrigation requirements) were simulated using CropWat8.

- ***Efficiency*** at scheme level:
  - Conveyance efficiency was determined by dividing the amount of irrigation water measured at selected up stream and downstream points at different hydraulic levels (main, secondary and tertiary where available).

  - Main canal:

    EC = discharge delivered to the secondary canal/ discharge pumped from river

  - Secondary canal:

    E_C = (discharge delivered to the tertiary/ discharge received by the secondary canal at the head end

- Tertiary canal:

  E_C = Q measured at plot level/ Q measured at the entrance of the tertiary canal

- Overall conveyance efficiency:

  E_C = Q measured at plot level/ Q measured at the entrance of the main canal

- ***At plot*** level:
  - Soil moisture difference (before and after irrigation) was determined for the some of the irrigation events of the sample plots to assess the amount of irrigation water applied and that retained within a root zone after irrigation.

Application efficiency was assessed for the sample plots by taking the ratio of the amount of water required to fill the soil moisture of the soil to its field capacity and the amount of water applied during some irrigation events. The soil moisture available prior to irrigation of some of the plots were measured using gravimetric method to calculate the amount required to fill and bring to its field capacity.

  - **E_a =** ***Depth of water added to the root zone/ Depth of water applied to the field***

- ***RWS:*** the ratio of the amount of water applied (rain+irrigation) and the amount of water required for optimum growth(from CropWat simulation) was calculated for each sample plots for each irrigation turn and averaged for the study period
  - ***RWS = Total water supply/ Crop demand according to CropWat***
    - Total water supply= Irrigation + rainfall (no contribution of groundwater is assumed)
- ***RIS:*** The ratio of the amount of irrigation water applied and the amount required for optimum growth:
  - ***RIS = Irrigation supply/ Irrigation demand according to CropWat***

- ***Irrigation interval***: Based on evapotranspiration and the soil characteristics, irrigation interval was obtained from CropWat simulation for optimum irrigation. Optimum irrigation in this case was assumed to be irrigating the crop when the soil moisture reaches the limit of readily available moisture(RAM) and filling the soil to its field capacity;

  - **Irrigation Interval =** ***Allowable soil mositure depletion/ ET_c***

- The ***total irrigation*** water required for the growing season was taken from the estimate of the CropWat model for the type of crops grown in the area during the study period (onion, tomato and pepper).

- Irrigation water abstracted (used) was estimated for the entire season based on the measurements (Q & T: V) during the study period and the energy used to operate the electric pump (KWH). Information found during the study period was complemented by an interviewing the respective stakes on the condition of water used during the period prior to the study of the same season.

- ***Irrigation efficiency*** was calculated by taking conveyance efficiency and application efficiency calculated above for the sample plots. The results obtained for different measurement points (sample plots) was assessed and analyzed to determine the condition at scheme level.

Ec, Ea, RWS, and RIS obtained at sample plots (measurement points) are analyzed to determine the above parameters at scheme level

  - $\mathbf{E = (E_c * E_a)/100}$

2.6 Materials used

Current meter (Propeller), Cut-throat flumes (2: 20 cm and 10cm width constructed using sheet metal), GPS, CropWat 8 model.

3. Results and discussion

3.1 Meteorological and crop data

No significant rainfall was observed during the study period May-June. Rainfall started in July. The reference evapotranspiration of the area ranges from 3.7 (in July) to 4.49 (in April) mm/day (Table 3.1).

Table 3.1 Daily reference crop-evapotranspiration values at Haleku.

Month	ETo(mm)	Month	ETo(mm)	Month	ETo(mm)
January	3.99	May	4.66	September	3.82
February	4.37	June	4.43	October	4.23
March	4.47	July	3.7	November	4.19
April	4.49	August	3.71	December	3.94

ETo= Reference crop evapo-transpirtation

3.2 Soil physical parameters

The soil texture in the project area is predominantly sandy loam except for one sample which was loamy sand (Table 3.2). The analysis shows that there is not much difference in the soil properties among the irrigation blocks and soil layers. These results confirm earlier unpublished reports.

Table 3.2 shows the texture, pH, ECe, Soil Organic matter content (SOM) at the sample plot. The soil pH is in the range of 8.19 and 8.63, ECe in the range of 0.076 to 0.245 and SOM in the range of 1.18 and 1.72%. The moisture holding capacity of the soil was determined using the SPAW model. Figure 3.1 shows a screenshot of the model to determine the soil moisture at field capacity (FC), wilting point (WP) and the total available water (TAW). The moisture content at FC, WP and RAW are 16.9%, 7.5% and 9.4%, respectively.

Table 3.2 Soil physical parameters of different plots in the project area.

Plot	Depth(cm)	pH H2O(1:2.5)	EC(mmhos/cm)	% SOM	Texture			
					%Sand	%Silt	%Clay	Class
A	0-30	8.52	0.147	1.31	63	26	11	Sandy loam
	30-60	8.19	0.245	1.65	73	20	7	Loam sand
B	0-30	8.43	0.125	1.85	69	22	9	Sandy loam
	30-60	8.63	0.166	1.18	63	28	9	Sandy loam
C	0-30	8.3	0.104	1.72	65	24	11	Sandy loam
	30-60	8.3	0.076	1.18	71	22	7	Sandy loam
Average		8.4	0.144	1.48	67	24	9	Sandy loam

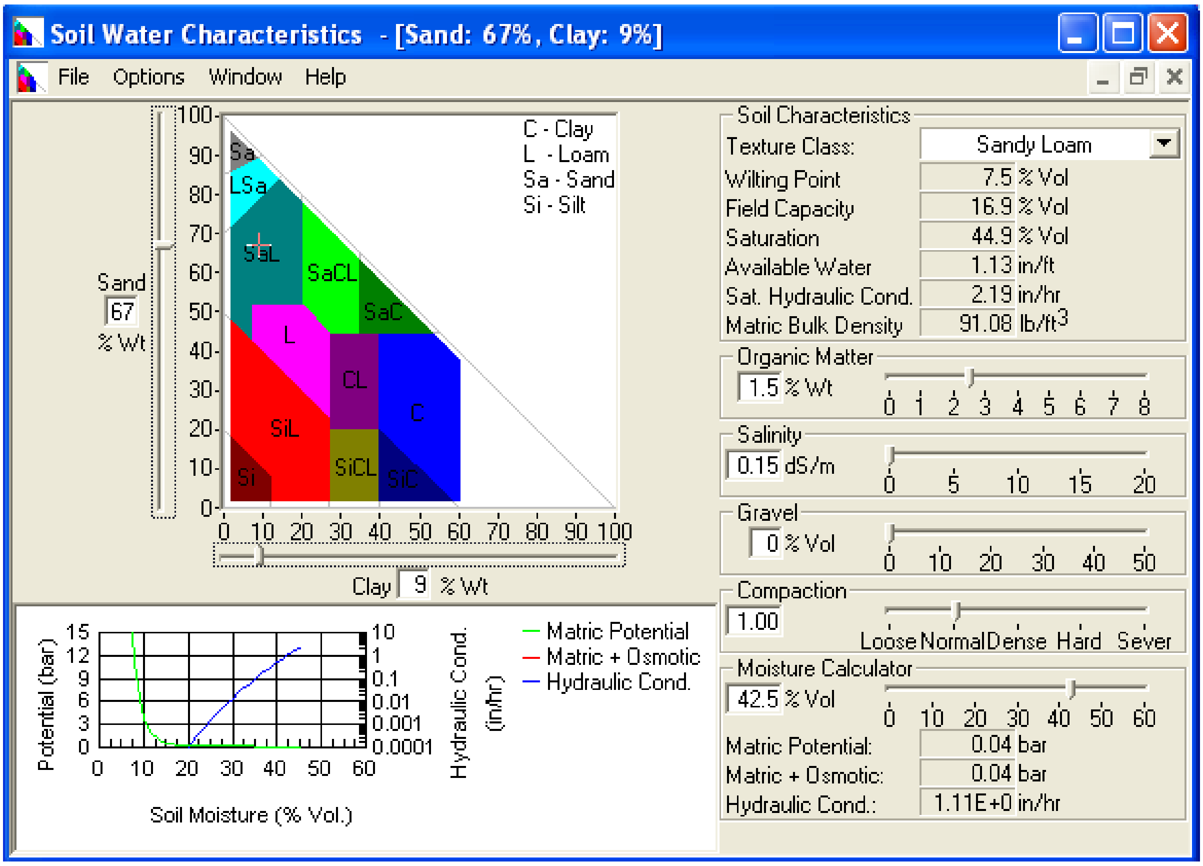

Fig. 3.1 Screenshot of SPAW model used to determine the moisture holding capacity of the soil at FC and PWP

3.3 Hydraulics characteristics of canals

The main canal has a length of about 1520 m. It is lined for about 0.5 km and the rest (1.02 km) is unlined but is planned to be lined in the near future with financial support from RCWD. The discharge in the main canal at the initial point is about 98 l/s. The size of the canal is enough to convey the current discharge and there is no danger of overtopping. There is a variation of the bed width of the canal measured at different section of the unlined part of the main canal. The average bed width for the lined and unlined part of the main canal is 49 and 87.5 cm, respectively. The average depth of the lined and unlined part of the main canal is 42 and 58 cm, respectively. These figures only indicate the average dimension of the main canal. There are parts of the main canal unlined with dimensions less than required to convey the anticipated discharge. This was clearly observed during the study period in which most of the water that came from the upper part overtopped the canals and flooded parts of adjacent fields.

Field (plot) and furrows

The size of the individual farmer fields range from 0.0625 to 0.25 ha which are distributed randomly within blocks. Each farmer may have plots in each block of 50 by 50m (0.25 ha) or 50 by 25 m (0.125 ha) or 25 by 25 m (0.0625 ha). Overall each farmer has a total of 0.5 ha, allocated within the three blocks. The furrow length commonly used in Haleku is short, about 6m. Some fields are irrigated by flooding (practiced by some farmers) even if there are furrows which are small in size to carry the amount of discharge received.

3.4 Irrigation scheduling, crop water and irrigation requirements

Irrigation management is carried out in rotation among the six groups in which the farmers are free to irrigate till they have received enough water. Irrigation intervals vary based on the crop stage and rainfall. The availability of water for upstream and downstream farmers is the same, i.e. there is ample water in the scheme. However, the downstream farmers irrigate for longer periods as compared to upstream farmers.

The irrigation interval in the initial period of the crops commonly grown in the area is about 3 days; while it increases to 4 and finally to 6 days at the end of the growing season. Unfortunately during the study period there was problem in the electric power which forced farmers to adapt longer irrigation intervals as compared to the one commonly practiced in the area.

Regarding scheduling, all six groups get water turn by turn and the method of water distribution is a rotational type. If electric power interruption hinders scheduling, farmers negotiate with other groups to get the required water. Some farmers irrigate according to the schedule but other farmers negotiate with other groups to use more or earlier irrigation water. If such farmers are granted water then they usually have to wait until all the group members with the right to irrigate finish irrigation, after which they can irrigate their own field.

The crop water requirements and irrigation requirement of the major crops grown during the study period, i.e. onion, tomato and pepper, are shown in Table 3.3. See Annex II and III on the details of irrigation requirements and scheduling.

The crop water requirement of onion which is planted (transplanted) at the beginning of March is estimated at 394 mm while the irrigation requirement is 318 mm as 72.4 mm of the water requirements are obtained from (effective) rainfall. The water requirement of tomato planted at the beginning of January is 484 mm, of which 115 mm is supplied by rainfall while the rest 367 mm need to be supplied by irrigation. The water requirement of pepper planted March is 500 mm of which 455 mm need to delivered through irrigation, the rest (46 mm) is from rainfall. The gross irrigation requirements of onion, tomato and pepper are 580, 620 and 758 mm, respectively (See Annex III).

Table 3.3 Crop water and irrigation requirements of the crops grown on the sample plots

Plot	Block	Type of Crop	Area (ha)	Planting date	First irrigation	Harvesting date	Etc (mm)	Eff. Rain (mm)	Irr. Req (mm)
A1	A	Onion	0.25	5-3-2008	4-3-2008	28-6-2008	392.4	42.9	349.5
A2	A	Onion	0.25	8-3-2008	7-3-2008	2-7-2008	392.3	49.4	342.9
A3	A	Onion	0.25	4-3-2008	3-3-2008	29-6-2008	392.5	37.7	354.8
B1	B	Tomato	0.25	12-3-2008	11-3-2008	8-7-2008	480.3	101.4	378.9
B2	B	Pepper	0.25	12-1-2008	11-1-2008	23-4-2008	496.1	41.1	455
B3	B	Onion	0.25	8-3-2008	7-3-2008	2-7-2008	392.3	49.4	342.9
C1	C	Onion	0.25	22-2-2008	21-2-2008	18-6-2008	391.5	38.2	353.3
C2	C	Tomato	0.125	1-4-2008	31-3-2008	5-6-2008	462.9	147.6	315.3
C3	C	Onion	0.125	14-3-2008	13-3-2008	9-7-2008	392.4	52.2	340.2

The moisture difference between soil moisture assessed before and after irrigation events showed that in general the amount of water applied is greater than what is required to fill the soil to its field capacity. According to the assessment done during the study period and information from the DA and farmers, members irrigate for long periods till they are sure that all parts of the plot got enough water. Most of the farmers follow the condition of their plot (soil condition) by making visual inspection and request their group leader or leader of other group to get water if they think that their field needs water. Other farmers ignore their turn of using irrigation water to minimize pumping costs, especially if they anticipate rain. Most of the time irrigation starts from the upper part. Upstream farmers within a group (Block A or B) that do not have a plot needing water are free to irrigate their downstream plots.

Table 3.4 shows the variation in number of irrigation events between plots which might be associated with the variation in production beside other difference in the management practices. For plots planted with onion, the number of irrigation events ranges from 19 to 33. The production and revenues obtained by the selected farmers in this study and some other best performing farmers are shown in Annex VI.

Table 3.4 Number of irrigation turns used by different farmers.

Plot	Block	Crop	Area(ha)	Planting date	Length of growing period(days)	No. of Irr. Turns/season
A1	A	Onion	0.25	5/3/2008	105	25
A2	A	Onion	0.25	8/3/2008	105	33
A3	A	Onion	0.25	4/3/2008	105	20
B1	B	Tomato	0.25	12/3/2008	120	32
B2	B	Pepper	0.25	12/1/2008	130	30
B3	B	Onion	0.25	8/3/2008	105	23
C1	C	Onion	0.25	22/2/2008	105	19
C2	C	Tomato	0.125	1/4/2008	120	31
C3	C	Onion	0.125	14/3/2008	105	19

3.5 Water requirement at abstraction

Currently, only the electric pump is used to irrigate crops in the scheme. The diesel pump is operated sometimes to irrigate crops in the nursery, which might be due to the high cost of fuel. Since April 2008 electricity is available 3 to 4 days a week due to power shortages in the country.

Water abstraction data

Water abstracted from the river for the period (the growing season) was estimated using the electricity use during the pump operating days. The total amount of water (m^3) was determined and compared with the amount of water needed to irrigate the crops. The 80% probability of rainfall was estimated from historical records to account for the contribution of rainfall to the crop water needs. The gross and net irrigation requirement was estimated for the growing season for the whole command area and the sample fields (plots). The total irrigated area and the type of crops grown was based on WUA records. The KWH assigned (allocated) to each farmer (plot) was taken from the groups and WUA's record. It was used to estimate the amount of water used by each farmer (sample, all command area) during the last irrigation season from March to June/July. The pump efficiency (electrical) was calculated using the water energy which is estimated by taking the power required to pump the water through the available head and the actual energy obtained from the meter. Accordingly, the head difference between the water and the point of pumping is 34 m including the suction head and the efficiency of the pump is 67% (Table 3.5).

Table 3.5 Head, water energy and efficiency of the pump.

Events	Q (m3/s)	Head (m) 1)	Water power (KW) 2)	Time (hrs)	Water energy used(KWH) 3)	Energy used (KWH)	Pumping efficiency (%)4
1	0.1	34	33.35	4.33	144.40	214	67
2	0.1	34	33.35	2.1	70.04	104.4	67

1) Including suction head of 3 m (Elevations at the pump station and the main canal are 1581 and 1612 m, respectively)
2) Calculated using the relationship: Water power (kW) = 9.81 x discharge (m^3/s) * head (m)
3) Calculated using the relation ship: Water energy (kWh) = water power (kW) * operating time (h)
4) Pumping plant efficiency (%) = (water energy / actual energy) * 100

Figure 3.2 shows the amount of water pumped per day in cubic meter versus the area irrigated per day in the last irrigation season (March to June). The amount of water pumped is linearly related to the area irrigated. The larger the area irrigated, the more irrigation water is pumped. But there are cases in which the amount of water pumped is high while the irrigated area was small. The graph also shows that for the same irrigated area per day the water pumped was not similar. Based on the group, i.e. farmers with experience or not, some farmers hire labourers who do not have irrigation skills the amount of water pumped varies.

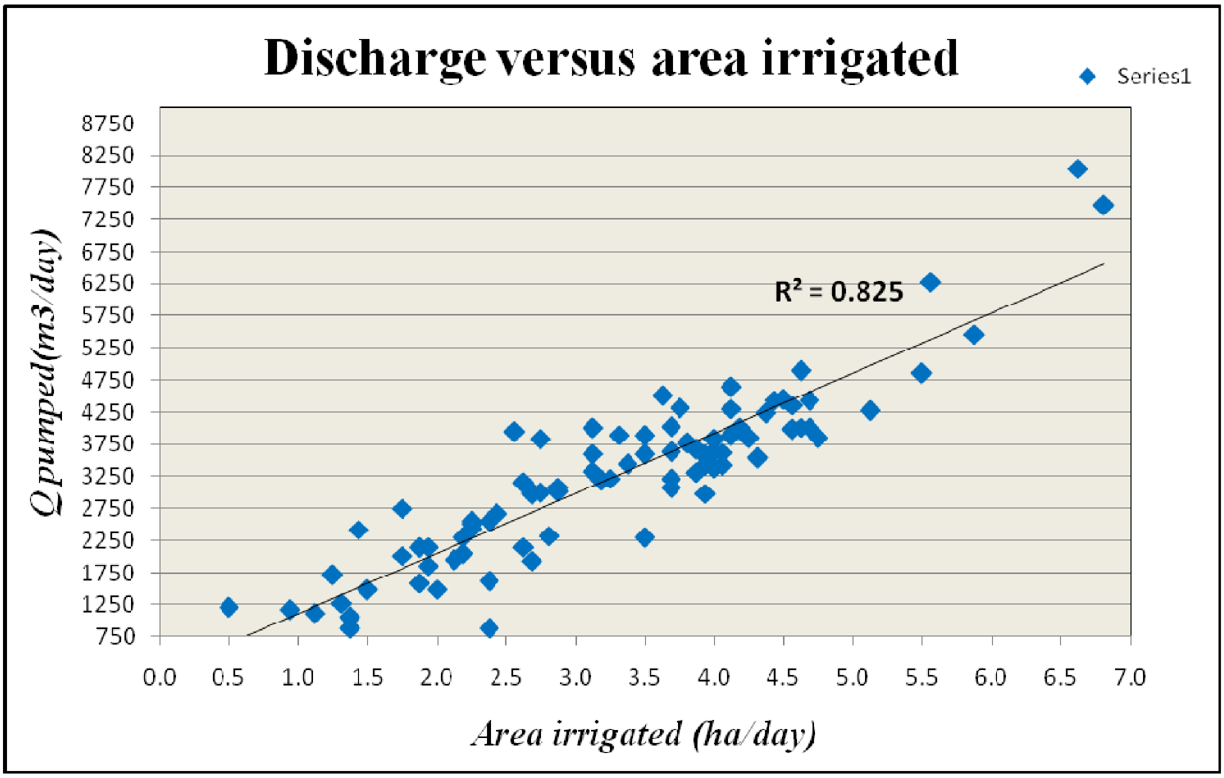

Figure 3.2 Irrigation water pumped and area irrigated for the season from March to July.
See Annex V for more information on the amount of irrigation water pumped, area irrigated, and energy used for pumping water.

3.6 Discharge, application time and irrigation depth

Farmers irrigate as many furrows as possible at a time irrespective of the discharge received. As the size of the furrow is small a lot of farmers flood part of a field from the top and wait till it covers a certain area and they continue until they finish their land. In some parts (fields) even if they let water via some number of furrows, the water overtops the furrows and floods the plot. This practice is common and observed in many fields during the study period (Annex VII).

Irrigation of fields is also not uniform. Some farmers start irrigation from the downstream side of the field while others start from the top part of the field from which they get water. But all farmers responded in interviews on their method as the most convenient way. As the furrow size is small, most furrows receive a discharge beyond their capacity. Consequently, water may spill over furrows and flow to a part of the field that has already been irrigated.

The discharge received at each plot varies from time to time as there is no measuring device for secondary or tertiary canals. Farmers negotiate on the amount of water that should flow along the secondary/tertiary canals. If farmers want to increase/decrease the amount of water that flows into a secondary or tertiary canal, they add or reduce straw/soil at the diversion point (Annex VII). If a farmer thinks that the amount of water he/she receives is lower, he/she goes to the diversion point and reduces the straw from the point that lets water to his/her field or he/she adds more straw/soil to the point that diverts water to other farmers. The addition of straw/soil is also used to stop irrigation quickly.

The application time mostly depends on the discharge received at a given point. Table 3.6 shows the time used to irrigate the sample plots ranging from 0.125 to 0.25 ha. In general, the application time is linearly related to the discharge amount.

The irrigation water depth of the sample plots with onion ranged from 20.7 to 34.2 mm (Table 3.6). Pepper fields received about 24 mm while tomato fields 18.6 to 29.5 mm. On average each field received 24.5 mm of irrigation water per irrigation event (Annex IV). This shows that there is not much difference on the amount of irrigation water applied during the study period. During the study period, the irrigation interval was about twice as long as the one commonly used (3-4 days) due to power interruption for about 10 days per month.

Table 3.6 Amount of irrigation water applied.

Plot	Q (m3/s)	A(m^2)	T(min)	applied gross water (m^3)	Gross irrigation depth (mm)	Total no. of irrigation	Total irrigation water appl. (mm)	Total Irrigation water app. (m^3)
A1	0.013	2500	112	85.47	34.2	25	855	8550
A2	0.010	2500	122	73.16	29.3	33	966	9660
A3	0.010	2500	102	62.99	25.2	20	504	5040
B1	0.006	2500	120	46.5	18.6	32	595	5950
B2	0.009	2500	114	60.08	24.0	30	721	7210
B3	0.007	2500	101	43.9	17.6	23	404	4040
C1	0.006	2500	111	51.9	20.7	19	393	3930
C2	0.009	1250	72	36.83	29.5	31	913	9130
C3	0.009	1250	59	31.35	25.1	19	476	4760

Water application

The amount of irrigation water applied per hectare in one irrigation season ranges from 327 mm (3270 m^3) to 966 mm (9660 m^3) for onion fields. For tomato the assessment of the sample plot showed that in one season 595 mm(5950 m^3) to 913 mm (9130 m^3)of water is applied and the amount of water applied for pepper is about 721 mm(7210 m^3) per hectare (Table 3.7). The average amount of irrigation water applied per hectare per season is 6400 m^3.

Table 3.7 Actual application volumes.

Plot	Gross depth (mm/irr. event)	Total no. of irrigation	Total gross irrigation applied (mm)	Total gross irrigation applied(m^3/ha/season)
A1	34.19	25	855	8550
A2	29.26	33	966	9660
A3	25.2	20	504	5040
B1	18.6	32	595	5950
B2	24.03	30	721	7210
B3	17.56	23	404	4040
C1	17.19	19	327	3270
C2	29.47	31	913	9130
C3	25.08	19	476	4760
Average	24.51	26	640	6401

3.7 Irrigation performance

3.7.1 Conveyance efficiency

Table 3.8 Losses per unit length of the main canal.

Plot	Q1 (l/s)	Q2 (l/s)	Dis. (m)	Loss(l/s/m)/Av)	Remark
A1	88.5	83.9	150	0.03	Lined
A2	98.8	94.7	375	0.01	Lined
A3	98.8	94.8	375	0.01	Lined
B1	72.1	45.3	415	0.06	Unlined
B2	68.8	43.0	110	0.23	Unlined
B3	38.0	33.8	110	0.04	Unlined
C1	27.3	21.7	50	0.11	Unlined
C2	23.4	19.5	110	0.04	Unlined
C3	18.8	14.4	100	0.04	Unlined

Table 3.8 to 3.10 show the losses per unit length of the main, secondary and tertiary canals. Table 3.8 indicates that the loss per length of the main canal for the lined part ranges from 0.01 to 0.03 l/s. The unlined part had a loss per meter distances that ranges from 0.04 to 0.23 l/s. The loss per meter of the secondary canal ranges from 0.02 to 0.32 l/s (Table 3.9). The loss per meter of the tertiary canals ranges from 0.04 to 0.22 l/s (Table 3.10).

Table 3.9 Conveyance losses per unit length of the secondary canals.

Plot	Q1 (l/s)	Q2 (l/s)	Dis. (m)	Average loss(l/s/m)
A1	18.7	13.8	15	0.32
A2	19.7	15.6	30	0.14
A3	39.4	34.2	30	0.17
B1	11.2	8.4	25	0.11
B2	12.4	10.0	110	0.02
B3	14.8	11.4	160	0.02
C1	10.7	9.5	25	0.05
C2	13.2	10.9	75	0.03
C3	14.4	10.6	185	0.02

Table 3.10 Conveyance losses per unit length of the tertiary canals.

Plot	Q1(l/s)	Q2(l/s)	Dis. (m)	Average loss (l/s/m)
A1	13.8	12.9	6	0.16
A2	13.7	9.0	125	0.04
A3	22.0	10.7	140	0.08
B1	8.4	7.3	10	0.11
B2	11.1	8.9	10	0.22
B3	11.4	9.3	12	0.18
C1	9.5	8.4	10	0.10
C2	10.9	9.3	8	0.20
C3	10.6	8.7	13	0.15

Table 3.11 shows the conveyance efficiency of the main, secondary and tertiary canals. The conveyance efficiency of the sample plots (main, secondary and tertiary) irrigated at the indicated day is shown. As the discharge delivered through the main canal might not go to one plot, the overall conveyance efficiency is calculated for the secondary and tertiary part that delivers water to one particular sample plot at a time. The conveyance efficiency of the lined part of the main canal that delivers water to sample plots (A1-A3) ranges from 91 to 96%. The unlined part (main canal) had conveyance efficiency in the range of 67 to 85% measured between two points of the main canal connecting the sample plots. Ec of B2 (for the main canal) shows the conveyance efficiency of the canal between B1 and the B2, etc.. On 19/06/08 was a huge loss due to canal breaching and overtopping of the water because only one upstream farmer was irrigating and the rest of the water was delivered downstream in which the conveyance efficiency for the part studied was 56%.

Except for two secondary inlets located at 375 and 525 m from the start of the main canal, which have pipes of diameter 20 and 10 cm, respectively, all secondary canals emerge from the main canal flowing alongside of the plots. Overall, the conveyance efficiency of the secondary canal was found to vary between 66 and 89% (Table 3.11). The higher values correspond to secondary canals that deliver water to plots closer to the main canal.

The tertiary canals assessed had a lot of overtopping and their conveyance efficiency varied between 40 and 95%. Two of the sample plots which are located at the middle and lower part of block A (Plot A2 and A3) receive water from the secondary canal 1 (pipe 1) located at 375 from the beginning of the main lined canal. The water travels 125 and 140 m to reach plot A2 and plot A3, respectively with great loss due to overtopping and seepage (Table 3.10 and 3.11). Overall, tertiary canals that cover longer distances such as the canal that delivers water to plot A3 had a lower conveyance efficiency, especially during days with high discharges.

The higher the amounts of irrigation water in the canal the lower the conveyance efficiency. Especially the middle and lower part of the main canal do not have the capacity to convey higher discharges and some of the water is lost by overtopping from the canal in addition to the water lost by seepage. The conveyance efficiency of the canal is higher for lower discharges conveyed in the canal. In the middle part of the main canal, losses were observed due to overtopping especially during days at which much of the water was conveyed downstream. During times in which a lot of farmers irrigate in the upper part (Block A), the amount of water that was conveyed was low and losses only due to seepage.

At the first two secondary canals formed by pipes and take water to the plots in the first block, the higher the amounts of irrigation water is the diverted from the main canal, the lower the conveyance efficiency. Especially the first pipe conveys a discharge which is greater than its capacity and overtopping and water loss by loose fitting of the pipe (rubber) is commonly observed during at days when more than two fields are irrigated at the same time.

The discharges that were delivered in the secondary canals at the point of diversion range from 11 to 54.7 l/s. The lower discharge correspond to the discharge delivered to one plot (farmer) and the higher discharge corresponds to discharges conveyed to three farmers located in different parts of block A and irrigating simultaneously from the same canal (pipe 1, A2, A3).

Most of the sample plot as well as the farmers in the project area take water directly from the main canal to the field supply canals that convey water to their plots. The length of the supply canal is short as compared to the size of the tertiary canal used by some farmers to bring water from the secondary canal to their fields. The maximum length of the field supply canal is around 50 m corresponding to the width of the plots owned by a single farmer. There was overtopping in the tertiary canals as well as in the field supply canals.

Table 3.11 Conveyance efficiency of the canals on daily basis.

Date	A2			A1			B1			C3		
22-05-08	Q(1)	Q(2)(l/s)	Ec(%)	Q(1)	Q(2)(l/s)	Ec(%)	Q(1)	Q(2)	Ec(%)	Q(1)	Q(2)	Ec(%)
Main canal	98.8	95.2	96	76.6	71.7	94	51.5	36	70	18.8	15.3	81
Secondary	18.6	15.7	84	20.2	13.4	66	9.7	7	72	15.3	11.7	76
Tertiary	15	10	67	13.4	12.7	95	7	6.5	93	11.7	8.9	76
Overall(Sec.&Ter.)			56			63			67			58
28-05-08	A2			B2			C1			C3		
	Q(1)	Q(2)(l/s)	Ec(%)	Q(1)	Q(2)(l/s)	Ec(%)	Q(1)	Q(2)	Ec(%)	Q(1)	Q(2)	Ec(%)
Main canal	98.8	94.8	96	77.3	54	70	38	32	84	18	13.7	76
Secondary	17.5	14.2	81	16	13.3	83	14	12.1	86	13.7	9.2	67
Tertiary	14.2	9	63	13.3	10.1	76	12.1	10.8	89	9.2	8.1	88
Overall(Sec.&Ter.)			51			63			76			59
31-05-08	A1			C2								
	Q(1)	Q(2)(l/s)	Ec(%)	Q(1)	Q(2)(l/s)	Ec(%)						
Main canal	98.8	90	91	17	14	82						
Secondary	17	13.8	81	14	11.6	83						
Tertiary	13.8	13	94	11.6	9.9	85						
Overall(Sec.&Ter.)			76			71						
05-06-08	B3											
	Q(1)	Q(2)(l/s)	Ec(%)									
Main canal	19	16.2	85									
Secondary	16.2	11.5	71									
Tertiary	11.5	9.3	81									
Overall(Sec.&Ter.)			57									
06-06-2008	A2			B2			C1					
	Q(1)	Q(2)(l/s)	Ec(%)	Q(1)	Q(2)(l/s)	Ec(%)	Q(1)	Q(2)	Ec(%)			
Main canal	98.8	94.2	95	71.2	32	45	21	14	67			
Secondary	23	17	74	11	8.7	79	8.5	7	82			
Tertiary	12	8.1	68	12	8.7	73	7	6.4	91			
Overall(Sec.&Ter.)			50			57			75			
08-06-08	A3											
	Q(1)	Q(2)(l/s)	Ec(%)									
Main canal	98.8	95.3	96									
Secondary	43	37.8	88									
Tertiary	26	10.3	40									
Overall(Sec.&Ter.)			35									

12-06-08	A1			B1			B2		
	Q(1)	Q(2)(l/s)	Ec(%)	Q(1)	Q(2)(l/s)	Ec(%)	Q(1)	Q(2)	Ec(%)
Main canal	98.8	89.9	91	74.5	58	78	58	43	74
Secondary	15.4	12.7	82	13	9.6	74	10.3	7.9	77
Tertiary	12.7	11.4	90	9.6	8.1	84	11	7.9	72
Overall(Sec.&Ter.)			74			62			55
14-06-08	B3			C2					
	Q(1)	Q(2)(l/s)	Ec(%)	Q(1)	Q(2)(l/s)	Ec(%)			
Main canal	38	32.3	85	15.3	11.9	78			
Secondary	13.4	10.3	77	11.8	9	76			
Tertiary	10.3	8.1	79	9	7.9	88			
Overall(Sec.&Ter.)			60			67			
18/06/2008	A3			A1					
	Q(1)	Q(2)(l/s)	Ec(%)	Q(1)	Q(2)(l/s)	Ec(%)			
Main canal	98.8	***94.2***	95	58.4	54.5	93			
Secondary	35.8	30.6	85	18.9	14.3	76			
Tertiary	18	11	61	14.3	12.9	90			
Overall(Sec.&Ter.)			52			68			
19/06/2008	B1			C1					
	Q(1)	Q(2)(l/s)	Ec(%)	Q(1)	Q(2)(l/s)	Ec(%)			
Main canal	75.3	42	56	23	19	83			
Secondary	11	8.6	78	10.5	9.3	89			
Tertiary	8.6	7.2	84	9.3	8.1	87			
Overall(Sec.&Ter.)			65			77			
21/06/2008	B3			C2			C3		
	Q(1)	Q(2)(l/s)	Ec(%)	Q(1)	Q(2)(l/s)	Ec(%)	Q(1)	Q(2)	Ec(%)
Main canal	57	52.8	93	38	32.5	86	18.6	14.3	77
Secondary	14.8	12.3	83	13.9	12.2	88	14.3	11	77
Tertiary	12.3	10.4	85	12.2	10.1	83	11	9	82
Overall(Sec.&Ter.)			70			73			63

The conveyance efficiency of the secondary and tertiary canal assessed for each sample plot was in the range of 50 to 77 % excluding one extreme case which was not common.

Table 3.12 shows the overall conveyance efficiency of the canals taking into account the contribution of the portion of the main canal that conveys to the sample plots, the secondary and tertiary canal that goes to a particular plot. For the contribution of the main canal, the losses between the reach of the canal between the elected samples are considered as the whole water in the main canal do not go only to a particular field only at a time. For each sample plot, the losses per unit length obtained for the main, secondary and tertiary canal are a combination of seepage and overtopping. Accordingly the conveyance efficiency of the canals by taking the losses at all hydraulic levels (main, secondary and tertiary canals) is found to be in the range of 37 to 65%.

Table 3.12 Average conveyance efficiency at all hydraulic levels.

Plot	Ec (main canal) %	Ec (secondary canal) %	Ec (tertiary canal) %	Ec (total) %
A1	95	74	93	65
A2	96	79	66	50
A3	96	87	48	40
B1	63	75	87	41
B2	62	80	74	37
B3	89	77	82	56
C1	79	89	89	63
C2	83	83	85	58
C3	77	74	82	46

3.7.2 Application efficiency

The application efficiencies range from 36 to 89 % (Table 3.13). It is possible to arrive at 100% application efficiency by applying small amounts of water and thus minimising deep percolation (= loss). As the furrow is closed from downstream side, there is no loss due to runoff. But in some fields there is runoff loss which flows to other parts of a field which is used by the same farmer (not considered a loss). In most cases farmers try to extend the interval between irrigation events to minimize the costs. But the amount of water applied by the farmers is higher than what is required to fill the soil to its field capacity. Even if the irrigation interval is longer than planned, the amount of irrigation water applied was higher than required. Some of this water is lost by deep percolation and the application efficiency accordingly is lower than 100%.

Table 3.13 Application efficiency of the sample plots.

Plot	D (gross, mm)	Applied water (Gross, m^3)	Area (m^2)	Total no. of Irr.	Total irri. app. (mm)	Total irr app. (m3/season)	Irr. requir. (mm/season)	Application eff. (%)
A1	34.2	85.5	2500	25	855	854.7	348	40.7
A2	29.3	73.2	2500	33	966	965.7	348	36.0
A3	25.2	63.0	2500	20	504	504	348	69.1
B1	18.6	46.5	2500	32	595	595.2	372	62.5
B2	24.0	60.1	2500	30	721	720.9	455	63.1
B3	17.6	43.9	2500	23	404	403.9	348	86.2
C1	17.2	43.0	2500	19	393	983.3	348	88.5
C2	29.5	36.8	1250	31	913	913.5	372	40.7
C3	25.1	31.3	1250	19	476	476.5	348	73.0

There is no advantage with regard to water availability as all farmers in all blocks are free to take as much water as they wish without any extra cost for water as compared to upstream farmers. As all farmers have a plot in all blocks, there is no difference between farmers. Water pumped is more than required and the total irrigated area is small as compared to the available water. If more land would be irrigated (as planned), competition between the upstream and downstream irrigators could occur. Currently, farmers irrigate their field within a given day and pay energy costs (for pumping) based on their land size: The used KWH per day is divided by the total plots irrigated within that day.

3.7.3 Irrigation efficiency

Efficiency in the use of irrigation water consists of various components and takes into account losses during conveyance and application to irrigation plots. The irrigation efficiency of the project was calculated by taking the conveyance efficiency (along all hydraulic levels) and application efficiency. The irrigation efficiency of the sample plots are in the range of 18 to 55% (Table 3.14).

Different components contribute to the low irrigation efficiency of the scheme. Sometimes, losses in the tertiary canal are higher than in the main and secondary canal even if the discharge conveyed is low. There were cases in which the tertiary canals conveyed a discharge higher beyond their capacity. Sometimes the discharge that is let via tertiary canals is higher than the discharge conveyed by secondary canals. In those cases, losses in the tertiary canal contributed to low irrigation efficiency. The second reason for the lower irrigation efficiency is the conveyance loss in the main canal at the lower part of the scheme (Table 3.11). The canal capacity is too small to convey the full discharge that is pumped. When many upstream farmers irrigate, the discharge that reaches the lower part is small and the loss is small as compared to when few upstream farmers abstract water and much water is lost by overtopping of the canal (Figure 3.3a, b, c).

Figure 3.3a b, c over topping of the main canal

Table 3.14 Irrigation efficiency of the sample plots.

Plot	Ec (%)	Ea (%)	Ei (%)
A1	65	41	27
A2	50	36	18
A3	40	69	28
B1	41	63	25
B2	37	63	23
B3	56	86	48
C1	63	89	55
C2	58	41	24
C3	46	73	31

Irrigation interval

Based on the data obtained during the study period and the historical record of the sample fields and other fields, the irrigation interval was 3 to 5 days. During the study period due to power interruptions, the irrigation interval was around 6 days.

3.7.4 RWS and RIS

Table 3.15 RWS and RIS of the sample plots.

Plot	*CWR (mm)*	*Irr. Req. (mm)*	*Irr. app. (mm)*	*Rainfall (mm)*	*RWS*	*RIS*
A1	392.4	349.5	855	79	2.38	2.45
A2	392.3	342.9	966	112	2.75	2.82
A3	392.5	354.8	504	98	1.53	1.42
B1	480.3	378.9	595	126	1.5	1.57
B2	496.1	455	721	47	1.55	1.58
B3	392.3	342.9	404	112	1.32	1.18
C1	391.5	353.3	393	80	1.21	1.11
C2	462.9	315.3	913	187	2.38	2.9
C3	392.4	340.2	476	125	1.53	1.4

Table 3.15 shows the relative water supply (RWS) and relative irrigation supply (RIS) of the sample plots. The relative water supply is the ratio of the amount of water applied via irrigation and rainfall, and the crop water requirement. It ranges from 1.21 (plot C1) to 2.75 (plot A2) for onion while for tomato it ranges from 1.5 (plot B1) to 2.38 (plot C2). Pepper has a RWS of about 1.55 (plot B2). The RIS for onion fields ranges from 1.11 (plot C1) to 2.82 (plot B2). The RiS of tomato plots (B1 and C2) are 1.57 and 2.9. The RIS for the pepper field (B2) is 1.58. Plot B2 has received a large amount of irrigation water as compared to other plots. Plot B2 had 32 irrigation events in one season. The RIS of tomato and pepper fields indicate higher amounts of irrigation water relative to their irrigation requirement as compared to onion fields.

3.8. Operation and management

Water distribution

Farmers divide water between upstream and downstream plots taking the conveyance losses into account. The share of water between farmers (canals) is based on the distance the water travels to reach a given plot. For downstream plots along a canal, high discharge (higher proportion) of water is let in by visually inspecting the discharge in the canal. This was observed between plots (farmers) within in the same block and between plots in different blocks. However, farmers do not know the exact amount of water supplied.

A farmer with a crop in all blocks irrigates all plots belonging to him/her in a given day in which his/her group is supposed to use the water. Some farmers may not have a plot in one of the blocks to be irrigated (if harvested or not planted). In that case, he/she irrigates only his/her plots with a crop and the electricity costs are based on these plots only. In practice, there are wide variations in type of crop and crop stage in a given block, but the share of the energy costs is based on the area irrigated in a given day.

Farmers may request water of other group's by contacting a group leader of the group that is supposed to get water. Farmers of a group often do not irrigate their plots within the same day, even if they are supposed to. There are different reasons. Some farmers try to reduce the cost of electricity for pumping by withholding irrigation especially if they think the soil is moist or if they expect rainfall.

The group leaders allow members of other groups to take water because starting the pump for few farmers is not allowed. If there are few farmers in the field to irrigate, the group leaders do not start the pump until more farmers show up. If these farmers do not show up, irrigation is postponed to the following day. This is a common phenomena especially at the end of irrigation season when some farmers stop irrigating their plots (after harvesting) or if farmers become busy with other activities like preparation of land for the rain fed plots located further away from the irrigation project. If a group lost its turn, it has to wait for its next turn or request other groups (group leaders) to get water. If this (using water in other group's turn) happens during a period of peak water demand or during dry days it creates conflicts between farmers.

With regard to the management of plots, some farmers (even leaders) do not manage their plots well and information from WUA and DA indicates that such farmers are sometimes appointed as group leaders to give them responsibility, but this is not always a success.

If farmers expect rain, they do not come to the field to irrigate, i.e. to minimize cost of electricity (discussed before). However, if rain does not happen, many farmers come to their fields the next day to irrigate. This sometimes creates conflicts between farmers (with in the same group or between different groups).

Cases in which farmers irrigate out of their turn are common. There is no force or obligation to irrigate only according schedule, i.e. in practice the water delivery is more flexible than the rigid rotational distribution system.. In theory, water distribution is rotational, but in practice, especially at the end of the growing season, farmers are flexible to request water even if it is not their group's turn. Flexibility to request water is possible since there is more water available than needed for the area under irrigation.

4. Conclusions

The assessment of the water use efficiencies in the irrigation scheme Haleku indicates that the availability of irrigation water is not a constraint and high amounts of water are diverted to the plots. During the study period there was enough water in the Bulbula river even during the dry time and a pump with a high capacity as compared to the area irrigated and low cost of electricity gives farmers the opportunity to apply more water than the crops require. Even if this irrigation project is one of better managed schemes as compared to other smallholder irrigation projects in the area (government supported schemes), the efficiency is low and there is much scope to improve its performance.

The conveyance efficiency of the scheme at all hydraulic levels (main, secondary and tertiary) is poor, even in the lined part of the main canal due to lack of maintenance. The relative water and irrigation supply for the scheme shows that there is great variation between farmer plots. The amount of water applied during irrigation events is much higher than what is required to fill the soil to field capacity. The application efficiency is also poor resulting in low irrigation efficiency.

The farmers do not take into account the amount of water wasted. They mainly consider the overall energy consumption of the pump which they pay based on the area (plot) they irrigate. Hence, there is no financial benefit for a farmer using only a small amount of water for his own plot. There is no incentive for a farmer that applies small amounts of water.

In general, based on the assessment carried out, it can be concluded that the Haleku irrigation project performs below its technical capacity and if certain measures are applied, there is a potential to improve its efficiency. As there is no shortage of water, the scheme has room to expand and to provide irrigation opportunities to the surrounding community relying on rain fed agriculture. To realise this, rather than using more pumps to increase the amount of water pumped, emphasis should be on maintenance of the canals and overall scheme management.

5. Recommendations

Improvement of the irrigation efficiency of the scheme needs tackling of all problems in the area of water management (‘software’) and the infrastructure (‘hardware’).

- The physical structure (size and capacity) of the irrigation project needs to be improved such as lining.
- Canal structures used for dividing water among plots should be given emphasis.
- Farmer should be given training on how to manage irrigation water by taking into account the type of crop and crop stage.
- Minimize the pump capacity (using a pump with less capacity or use the current pump for shorter periods) to match better supply and crop demand.

The capacity of the pump needs to be decreased in order to minimize the amount of water wasted or more command areas as planned can be added to use the pump with its maximum (optimum) capacity. However, considering the over-exploitation of water resources in the Central Rift Valley (Jansen et al., 2007), this latter may be a less desired option.

- The RWS should be decreased to 1.5 or less. To do this, more land needs to be added or the capacity of the pump decreased. In that case, a pump with lower capacity should be used. But decreasing the capacity of the pump is not practical.
- Design a fair cost system based on the amount of water that farmers actually use. In order to make this practical, measuring devices are important.
- Train farmers to manage and use water more efficiently according to the actual crop water requirements.
- Use secondary canals instead of convey water in tertiary canals over long distances.

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7. Annexes

Annex I . Location and altitude of the sample plots and parts of the project.

Location	Latitude(° ' ")	Longitude(° ' ")	Altitude(m)
Pump station	7° 50' 28.9"	38° 43' 00"	1581
Office	7° 50' 29.3"	38° 42' 58.3"	1626
Main canal(0+00)	7° 50' 31.4"	38° 42' 51.5"	1612
A1	7° 50' 37"	38° 42' 34.4"	1648
A2	7° 50' 38.3"	38° 42' 39.5"	1648
A3	7° 50' 41.9"	38° 42' 47.8"	1647
B1	7° 50' 47.5"	38° 42' 39.1"	1649
B2	7° 50' 51.0"	38° 42' 42.6"	1649
B3	7° 50' 52.0"	38° 42' 45.3"	1647
C1	7° 50' 56.3"	38° 42' 43.8"	1647
C2	7° 50' 58.8"	38° 42' 46.6"	1646

Annex II. Crop and irrigation requirements of the major crops (CropWat 8)

a. Onion:

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Mar	1	Init	0.7	3.11	18.6	0.5	18.2
Mar	2	Init	0.7	3.13	31.3	1.3	30
Mar	3	Deve	0.72	3.21	35.3	3.8	31.5
Apr	1	Deve	0.78	3.52	35.2	7.5	27.7
Apr	2	Deve	0.85	3.82	38.2	10.2	28
Apr	3	Deve	0.92	4.18	41.8	9.1	32.7
May	1	Mid	0.98	4.53	45.3	6.7	38.6
May	2	Mid	1	4.68	46.8	5.6	41.1
May	3	Mid	1	4.6	50.6	8.2	42.4
Jun	1	Late	0.83	3.76	37.6	10.6	27
Jun	2	Late	0.44	1.95	13.7	8.8	1.1
					394	72.4	318

b. Tomato

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Mar	2	Init	0.6	2.68	24.2	1.2	22.9
Mar	3	Init	0.6	2.69	29.6	3.8	25.7
Apr	1	Init	0.6	2.69	26.9	7.5	19.4
Apr	2	Deve	0.69	3.08	30.8	10.2	20.6
Apr	3	Deve	0.84	3.84	38.4	9.1	29.3
May	1	Deve	1	4.61	46.1	6.7	39.3
May	2	Mid	1.13	5.29	52.9	5.6	47.3
May	3	Mid	1.15	5.27	58	8.2	49.8
Jun	1	Mid	1.15	5.19	51.9	10.6	41.2
Jun	2	Late	1.15	5.09	50.9	12.5	38.4
Jun	3	Late	1.04	4.34	43.4	17.3	26.1
Jul	1	Late	0.87	3.43	30.9	21.6	6.8
					484	115	367

c. Pepper

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jan	2	Init	0.6	2.38	21.4	0	21.4
Jan	3	Init	0.6	2.46	27.1	0	27.1
Feb	1	Init	0.6	2.54	25.4	0	25.4
Feb	2	Deve	0.66	2.89	28.9	0	28.9
Feb	3	Deve	0.76	3.36	26.9	0.1	26.8
Mar	1	Deve	0.86	3.84	38.4	0.9	37.5
Mar	2	Deve	0.98	4.37	43.7	1.3	42.4
Mar	3	Mid	1.05	4.7	51.7	3.8	47.8
Apr	1	Mid	1.05	4.71	47.1	7.5	39.6
Apr	2	Mid	1.05	4.71	47.1	10.2	36.9
Apr	3	Mid	1.05	4.77	47.7	9.1	38.6
May	1	Late	1.02	4.68	46.8	6.7	40.1
May	2	Late	0.94	4.39	43.9	5.6	38.3
May	3	Late	0.9	4.13	4.1	0.7	4.1
					500	46	455

Annex III. Irrigation scheduling of Onion/Tomato/Pepper

a. Onion

Date	Day	Stage	Rain	Ks	ETa	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
7-Mar	3	Init	0.4	1	100	30	8.9	0	0	15	0.57
10-Mar	6	Init	0	1	100	31	9.3	0	0	16	0.6
13-Mar	9	Init	0.6	1	100	28	8.8	0	0	15	0.56
16-Mar	12	Init	0	1	100	29	9.4	0	0	16	0.6
19-Mar	15	Init	0	1	100	29	9.4	0	0	16	0.6
22-Mar	18	Init	0	1	100	28	9.6	0	0	16	0.61
25-Mar	21	Dev	0	1	100	28	9.6	0	0	16	0.62
29-Mar	25	Dev	0	1	100	30	10.9	0	0	18	0.52
1-Apr	28	Dev	0	1	100	27	9.9	0	0	17	0.64
5-Apr	32	Dev	0	1	100	28	10.5	0	0	18	0.51
9-Apr	36	Dev	0	1	100	27	10.5	0	0	18	0.51
12-Apr	39	Dev	0	1	100	28	11.2	0	0	19	0.72
15-Apr	42	Dev	0	1	100	28	11.5	0	0	19	0.74
19-Apr	46	Dev	0	1	100	27	11.5	0	0	19	0.55
22-Apr	49	Dev	0	1	100	28	12.2	0	0	20	0.78
25-Apr	52	Dev	0	1	100	29	12.5	0	0	21	0.81
29-Apr	56	Dev	0	1	100	28	12.5	0	0	21	0.6
2-May	59	Dev	0	1	100	29	13.2	0	0	22	0.85
5-May	62	Dev	0	1	100	29	13.6	0	0	23	0.87
9-May	66	Mid	0	1	100	31	14.7	0	0	24	0.71
12-May	69	Mid	0	1	100	29	13.9	0	0	23	0.89
15-May	72	Mid	0	1	100	30	14	0	0	23	0.9
19-May	76	Mid	0	1	100	33	15.8	0	0	26	0.76
22-May	79	Mid	0	1	100	29	13.9	0	0	23	0.89
25-May	82	Mid	0	1	100	29	13.8	0	0	23	0.89
29-May	86	Mid	0	1	100	30	14.1	0	0	24	0.68
1-Jun	89	Mid	0	1	100	27	13	0	0	22	0.83
6-Jun	94	End	0	1	100	32	15	0	0	25	0.58
10-Jun	98	End	0	1	100	32	15	0	0	25	0.73
17-Jun	End	End	0	1	0	3					

b. Tomato

Date	Day	Stage	Rain	Ks	ETa	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
15-Mar	4	Init	0	1	100	40	10.1	0	0	17	0.49
19-Mar	8	Init	0	1	100	38	10.1	0	0	17	0.49
23-Mar	12	Init	2	1	100	31	8.8	0	0	15	0.42
28-Mar	17	Init	0	1	100	38	11.5	0	0	19	0.44
1-Apr	21	Init	0	1	100	34	10.8	0	0	18	0.52
6-Apr	26	Init	0	1	100	32	10.8	0	0	18	0.42
10-Apr	30	Init	0	1	100	31	10.8	0	0	18	0.52
16-Apr	36	Dev	0	1	100	36	13.1	0	0	22	0.42
21-Apr	41	Dev	0	1	100	42	16.2	0	0	27	0.62
26-Apr	46	Dev	0	1	100	38	15.3	0	0	26	0.59
30-Apr	50	Dev	0	1	100	37	15.3	0	0	26	0.74
5-May	55	Dev	0	1	100	45	19.6	0	0	33	0.75
10-May	60	Dev	0	1	100	43	19.6	0	0	33	0.75
15-May	65	Dev	0	1	100	50	23.6	0	0	39	0.91
20-May	70	Mid	0	1	100	50	23.6	0	0	39	0.91
25-May	75	Mid	0	1	100	46	22.1	0	0	37	0.85
30-May	80	Mid	0	1	100	46	22.1	0	0	37	0.85
4-Jun	85	Mid	0	1	100	43	20.5	0	0	34	0.79
9-Jun	90	Mid	0	1	100	43	20.4	0	0	34	0.79
14-Jun	95	Mid	0	1	100	40	19	0	0	32	0.73
20-Jun	101	End	0	1	100	51	24	0	0	40	0.77
30-Jun	111	End	0	1	100	53	25.1	0	0	42	0.48
9-Jul	End	End	0	1	0	14					

c. Pepper

Date	Day	Stage	Rain	Ks	ETa	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow

			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
14-Jan	3	Init	0	1	100	29	7.1	0	0	12	0.46
17-Jan	6	Init	0	1	100	28	7.1	0	0	12	0.46
20-Jan	9	Init	0	1	100	27	7.1	0	0	12	0.46
23-Jan	12	Init	0	1	100	27	7.4	0	0	12	0.47
26-Jan	15	Init	0	1	100	26	7.4	0	0	12	0.47
29-Jan	18	Init	0	1	100	25	7.4	0	0	12	0.47
1-Feb	21	Init	0	1	100	24	7.5	0	0	12	0.48
4-Feb	24	Init	0	1	100	24	7.6	0	0	13	0.49
7-Feb	27	Init	0	1	100	23	7.6	0	0	13	0.49
10-Feb	30	Init	0	1	100	22	7.6	0	0	13	0.49
13-Feb	33	Dev	0	1	100	25	8.7	0	0	14	0.56
16-Feb	36	Dev	0	1	100	24	8.7	0	0	14	0.56
19-Feb	39	Dev	0	1	100	23	8.7	0	0	14	0.56
22-Feb	42	Dev	0	1	100	25	9.6	0	0	16	0.62
25-Feb	45	Dev	0	1	100	26	10.1	0	0	17	0.65
28-Feb	48	Dev	0	1	100	25	10	0	0	17	0.64
3-Mar	51	Dev	0.4	1	100	27	11.1	0	0	19	0.71
6-Mar	54	Dev	0	1	100	27	11.5	0	0	19	0.74
10-Mar	58	Dev	0	1	100	35	15.3	0	0	26	0.74
13-Mar	61	Dev	0.6	1	100	28	12.5	0	0	21	0.8
16-Mar	64	Dev	0	1	100	29	13.1	0	0	22	0.84
20-Mar	68	Dev	0	1	100	37	17.5	0	0	29	0.84
24-Mar	72	Mid	0	1	100	35	16.8	0	0	28	0.81
28-Mar	76	Mid	0	1	100	35	16.8	0	0	28	0.81
1-Apr	80	Mid	0	1	100	40	18.8	0	0	31	0.91
5-Apr	84	Mid	0	1	100	31	14.9	0	0	25	0.72
9-Apr	88	Mid	0	1	100	31	14.9	0	0	25	0.72
14-Apr	93	Mid	0	1	100	38	18.2	0	0	30	0.7
19-Apr	98	Mid	0	1	100	38	18.2	0	0	30	0.7
22-Apr	101	Mid	0	1	100	30	14.3	0	0	24	0.92
25-Apr	104	Mid	0	1	100	30	14.3	0	0	24	0.92
29-Apr	108	Mid	0	1	100	30	14.3	0	0	24	0.69
3-May	112	End	3.5	1	100	32	15.3	0	0	26	0.74
8-May	117	End	0	1	100	42	19.9	0	0	33	0.77
14-May	123	End	0	1	100	51	24.1	0	0	40	0.77
20-May	129	End	0	1	100	49	23.5	0	0	39	0.75
21-May	End	End	0	1	0	0					

Annex IV. Irrigation water supplied to the sample plots.

Plot A1	Q(l/s)	Q(m3/s)	A(m2)	T(min)	V app (gross)(m3)	D(mm)	Plot B3	Q(l/s)	Q(m3/s)	A(m2)	V App. (gross)(m3)	D(mm)
22/05/2008	12.7	0.0127	2500	110	83.82	33.53	05/06/2008	7.8	0.008	2500	58.968	23.6
31/05/2008	13.0	0.013	2500	124	96.72	38.69	14/06/2008	6.5	0.007	2500	38.61	15.4
12/06/2008	12.0	0.012	2500	118	84.96	33.98	21/06/2008	7.2	0.007	2500	34.128	13.7
18/06/2008	13.4	0.0134	2500	95	76.38	30.55	Average	7.2	0.007	2500	43.902	17.6
Average	12.8	0.0128	2500	111.75	85.47	34.19	Plot C1					
Plot A2							28/05/2008	8.0	0.008	2500	45.954	18.4
22/05/2008	10.0	0.01	2500	123	73.8	29.52	06/06/2008	7.5	0.008	2500	47.25	18.9
28/05/2008	9.5	0.0095	2500	134	76.38	30.55	19/06/2008	8.0	0.008	2500	35.712	14.3
6/6/2008	10.5	0.0105	2500	110	69.3	27.72	Average	7.8	0.008	2500	42.972	17.2
Average	10.0	0.01	2500	122.33	73.16	29.26	Plot C2					
Plot A3							31/05/2008	7.9	0.008	1250	46.452	37.2
08/06/2008	11.1	0.0111	2500	85	56.61	22.64	14/06/2008	8.6	0.009	1250	36.12	28.9
12/06/2008	10.2	0.0102	2500	125	76.5	30.6	21/06/2008	9.5	0.01	1250	27.93	22.3
18/06/2008	9.7	0.0097	2500	96	55.87	22.35	Average	8.7	0.009	1250	36.834	29.5
Average	10.3	0.0103	2500	102	62.99	25.2	Plot C3					
Plot B1							22/05/2008	8.9	0.009	1250	27.768	22.2
22/05/2008	6.5	0.0065	2500	105	40.95	16.38	28/05/2008	8.1	0.008	1250	32.076	25.7
12/06/2008	7.4	0.0074	2500	136	60.38	24.15	21/06/2008	9.5	0.01	1250	34.2	27.4
19/06/2008	5.3	0.0053	2500	120	38.16	15.26	Average	8.8	0.009	1250	31.348	25.1
Average	6.4	0.0064	2500	120.33	46.5	18.6	Average(all)	8.8	0.009	2222.222	53.695	24.5
Plot B2												
28/05/2008	9.7	0.0097	2500	122	71	28.4						
06/06/2008	8.7	0.0087	2500	113	58.99	23.59						
12/06/2008	7.9	0.0079	2500	106	50.24	20.1						
Average	8.8	0.0088	2500	113.67	60.08	24.03						

Annex V Energy used and amount of irrigation water pumped using the electric pumps/season

Date	Area (ha)	Actual energy (KWH)	Water energy (KWH) /Eff=0.67/	Operating time (hr)	Q(m3)	Date	Area (ha)	Actual energy (KWH)	Water energy (KWH, eff=0.7)	Operating Time (hr)	Q(m3)
March 1, 2008	1.5	198	132.7	4.1	1485.3	April 13, 2008	4.1	518	347.1	10.8	3885.7
March 2, 2008	2.4	117	78.4	2.4	877.7	April 14, 2008	2.9	411	275.4	8.6	3083.1
March 3, 2008	2.6	287	192.3	6.0	2152.9	April 15, 2008	3.9	398	266.7	8.3	2985.5
March 4, 2008	2.9	402	269.3	8.4	3015.5	April 17, 2008	4.6	652	436.8	13.6	4890.9
March 6, 2008	1.3	171	114.6	3.6	1282.7	April 18, 2008	3.9	457	306.2	9.5	3428.1
March 7, 2008	4.0	451	302.2	9.4	3383.1	April 20, 2008	4.4	564	377.9	11.8	4230.8
March 8, 2008	4.3	471	315.6	9.8	3533.1	April 21, 2008	3.7	484	324.3	10.1	3630.7
March 10, 2008	3.2	425	284.8	8.9	3188.1	April 22, 2008	4.0	484	324.3	10.1	3630.7
March 11, 2008	0.9	156	104.5	3.3	1170.2	April 23, 2008	5.5	648	434.2	13.5	4860.9
March 12, 2008	2.6	526	352.4	11.0	3945.7	April 24, 2008	4.7	533	357.1	11.1	3998.2
March 13, 2008	3.5	480	321.6	10.0	3600.6	April 27, 2008	1.9	248	166.2	5.2	1860.3
March 14, 2008		481	322.3	10.0	3608.1	April 28, 2008	3.7	537	359.8	11.2	4028.2
March 15, 2008	2.2	272	182.2	5.7	2040.4	April 29, 2008	3.8	502	336.3	10.5	3765.7
March 16, 2008	2.3	334	223.8	7.0	2505.5	May 1, 2008	4.3	513	343.7	10.7	3848.2
March 17, 2008	3.3	429	287.4	8.9	3218.1	May 2, 2008	2.8	310	207.7	6.5	2325.4
March 18, 2008	5.1	570	381.9	11.9	4275.8	May 14, 2008	2.8	510	341.7	10.6	3825.7
March 19, 2008	3.7	428	286.8	8.9	3210.6	May 15, 2008	5.9	729	488.4	15.2	5468.5
March 20, 2008	2.7	396	265.3	8.3	2970.5	May 18, 2008	6.6	1073	718.9	22.4	8048.9
March 21, 2008	2.4	216	144.7	4.5	1620.3	May 19, 2008	4.1	483	323.6	10.1	3623.2
March 22, 2008	4.6	535	358.5	11.1	4013.2	May 20, 2008	2.4	340	227.8	7.1	2550.5
March 23, 2008		575	385.3	12.0	4313.3	May 21, 2008	4.1	456	305.5	9.5	3420.6
March 24, 2008	3.7	410	274.7	8.5	3075.6	May 22, 2008	4.5	593	397.3	12.4	4448.3
March 25, 2008	1.9	212	142.0	4.4	1590.3	May 24, 2008	5.6	837	560.8	17.4	6278.6
March 26, 2008	1.9	287	192.3	6.0	2152.9	May 25, 2008	6.8	997	668.0	20.8	7478.8

March 27, 2008	3.9	442	296.1	9.2	3315.6	May 28, 2008	4.0	510	341.7	10.6	3825.7
March 28, 2008	4.1	619	414.7	12.9	4643.3	May 29, 2008	4.6	581	389.3	12.1	4358.3
March 29, 2008	4.8	513	343.7	10.7	3848.2	May 30, 2008	1.1	148	99.2	3.1	1110.2
March 30, 2008	4.7	590	395.3	12.3	4425.8	May 31, 2008	4.1	574	384.6	12.0	4305.8
March 31, 2008	3.9	477	319.6	9.9	3578.1	June 1, 2008	3.6	601	402.7	12.5	4508.3
April 1, 2008	1.3	228	152.8	4.8	1710.3	June 6, 2008	2.6	420	281.4	8.8	3150.6
April 2, 2008	3.4	459	307.5	9.6	3443.1	June 7, 2008	2.7	258	172.9	5.4	1935.3
April 3, 2008	3.5	518	347.1	10.8	3885.7	June 12, 2008	4.2	534	357.8	11.1	4005.7
April 4, 2008	2.0	199	133.3	4.1	1492.8	June 13, 2008	2.7	399	267.3	8.3	2993.0
April 5, 2008	3.3	520	348.4	10.8	3900.7	June 14, 2008	3.1	445	298.2	9.3	3338.1
April 6, 2008	2.8	399	267.3	8.3	2993.0	June 19, 2008	2.4	356	247.4	7.4	2670.5
April 7, 2008	3.1	534	357.8	11.1	4005.7	Total	252.5	34042.0	22817.0	709.3	255360.9
April 9, 2008	4.4	592	396.6	12.3	4440.8	Max	6.8	1073.0	718.9	22.4	8048.9
April 10, 2008	3.9	489	327.6	10.2	3668.2	Min	0.9	117.0	78.4	2.4	877.7
April 12, 2008	4.6	531	355.8	11.1	3983.2	Average	3.5	460.0	308.3	9.6	3450.8

Annex VI. Revenue and cost of production

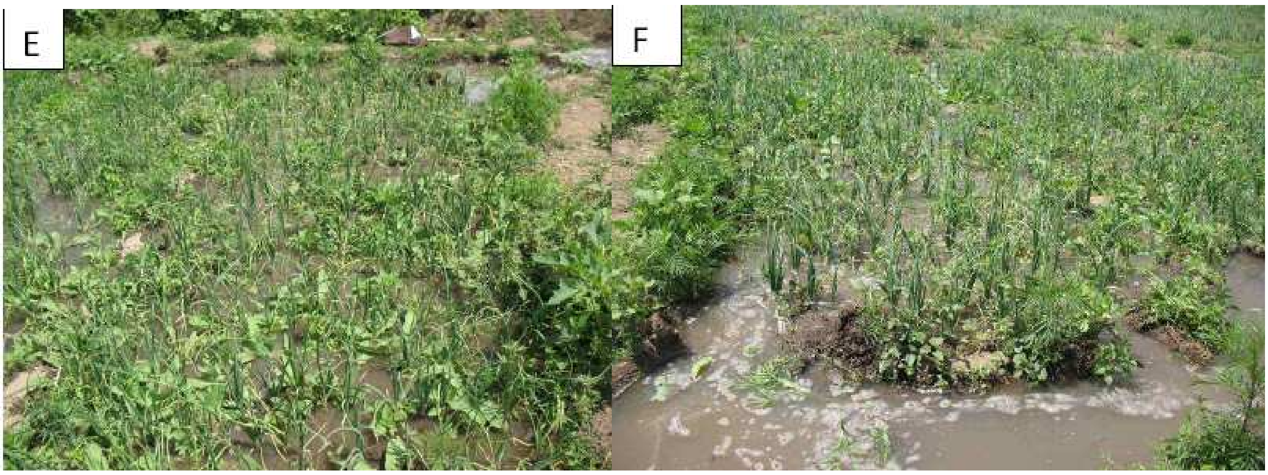
Plot	Block	Type of Crop	Area(ha)	Irr. App.(mm)	Total prod.(qt)	Price(Birr/Kg)*	Total sale(Birr)	Total sale(Euro)
A1	A	Onion	0.25	654.8	18	3.2	5765	377.57
A2	A	Onion	0.25	797.9	25	3	7515	492.23
A3	A	Onion	0.25	453.3	47	3.2	15053	985.97
B1	B	Tomato	0.25	798.8	78	0.7	5450	356.98
B2	B	Pepper	0.25	923.5	7	5	3500	229.25
B3	B	Onion	0.25	580.6	24	3.2	7797	510.68
C1	C	Onion	0.25	534.6	26	2.8	7218	472.80
C2	C	Tomato	0.125	904.6	25	0.7	1750	114.63
C3	C	Onion	0.125	534.3	26	3.4	8720	571.16

* 1.00 Ethiopian Birr is equivalent to 0.065 EUR

Annex VII Figures

A& B: Trees (straws) for controlling

C & D: The water has many routes



E & F: No furrow (flooding)