Mekelle University

School of Graduate Studies

Faculty of Dryland Agriculture and Natural Resources

The role of Household Ponds on the expansion of Homegardens in Tigray, Ethiopia

By

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A thesis

Submitted in partial fulfillment for the degree of

Masters of Science

In

Tropical Land Resource Management

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December, 2005

DECLARATION

This is to certify that this thesis entitled "**The role of Household on the expansion of Homegardens in Tigray, Ethiopia**" submitted in the partial fulfillment of the requirements for the award of the degree of M.Sc., in Tropical Land Resource Management to the School of Graduate Studies, Mekelle University, through the Department of Land Resource Management and Environmental protection, done by **Mr. Gebreegziabher Lemma Hagos, Id. No. FDA/PG04/96** is an authentic work carried by him under my guidance. The matter embodied in this project work has not been submitted earlier for award of any degree or diploma to the best of my knowledge and belief.

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ABSTRACT

In three districts of Tigray, northern part of Ethiopia, namely: Hintalo Wajerate, Kilte Awulaelo, Atsbi Wonberta, a study was conducted to assess the role of household ponds on the expansion of homegarden and to evaluate the water productivity of household ponds. The methods that were employed for the study were semi structured questionnaire, field observation, tree inventory, tree growth measurement and analysis of water productivity of ponds by using water balance models and water use efficiency indicators. Accordingly, the result of the study indicated that the construction of household ponds has a great contribution on the expansion of homegardens. The survival and growth of trees has improved by 15 % and 22 % respectively and the diversity of trees planted has shown a significant increase. Furthermore, the water productivity result indicated that the unit crop production per unit supplementary irrigation applied was 75% lower than the maximum potential water productivity; and the average economic productivity of the pond was estimated to be 3.8 ETB per cubic meter of water. The study reveals that among the reasons for low water productivity were inefficient water application and withdrawal method, poor knowledge of irrigation scheduling, poor selection of crop type and cropping calendar. It was also tried to quantify some problems in relation to design and implementation approach. Accordingly, because of the poor design (Trapezoidal shape) the average evaporation loss directly from the ponds was 13 % of the harvested water and the space occupied by the ponds is about 40 % of the land available in their backyard. Hence, household ponds are more effective and productive when they are constructed near homesteads for better management. To minimize the direct evaporation loss and space occupied by trapezoidal ponds other alternatives design needs to be considered. Moreover, in order to improve the water productivity, introduction of simple family drip irrigation system and acquainting farmers with scientific irrigation water management system could be among the better options.

Key words: Household ponds, homegarden, water productivity, water accounting, water balance, supplementary irrigation, and crop water requirement.

ACKNOWLEDGEMENT

I would like to express my sincere thanks to my advisors, Dr. Mintesinot Behailu, Dr. Nata Tadesse, Dr. Kindeya G/hiwot and Dr Eyasu Elias, for their scientific guidance and support throughout the study. My sincere gratitude also extends to Muluberhan Haile, Degole Fissehaye , Edris Mohamed, Samual Yehedego and Akelelu H/micheal, for their valuable insight and comments. I am very grateful to Shewanesh Lemma, Ezgimelese T/Abe, Hailu Abay and Samson Atsebha, for their help in data entry and provision of the necessary information.

This study would not have been possible without the financial support of ICRAF (World Agroforestry Center) for which I am very grateful. I want to extend my gratitude to all members of ICRAF Addis Ababa and GTZ SUN Tigray for their friendly support. Lastly, I would like to thank you all for your invaluable contribution, which will never go unforgotten.

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ABBRIVATIONS AND ACRONYMS

REST	Relief Society of Tigray
TWRB	Tigray Water Resource Bureau
BoANR	Bureau of Agriculture and natural Resource
GTZ	German Technical Cooperation
SFPT	Social Forestry Project Tigray
Woreda	District
MoA	Ministry of Agriculture
Kushet	Village
PET	Potential Evapotranspiration
AET	Actual Evapotranspiration
CWR	Crop Water Requirement
WP	Water Productivity
SM	Soil Moisture
PWP	Permanent Wilting Point
FC	Field Capacity
TAW	Total Available Water
RAW	Readily Available Water
KC	Crop Coefficient
ANOVA	Analysis of Variance
Df	Degree of freedom
M	Mean
N	No. of population

Sig.	Level of significance
ICRAF	World Agroforestry Center
IWMI	International Water Management Institute
MU	Mekelle University
SPSS	Statistical Program for Social Sciences
FAO	Food and Agricultural Organization
RELM	Regional Land management Unit
ETB	Ethiopian Birr
HB	Hailay Abreha
LK	Lemmlem Kahessay
HA	Hagos Amare
SW	Seyum Wahid
HM	Hadish Mebrahtom
AT	Amare Teare

Chapter I: Introduction

The most important characteristics of semi arid and arid areas are the factors, which limit availability of adequate soil moisture for plant growth. These include: high temperatures, low humidity, intense sunlight and high winds. These factors encourage very high rate of potential evapotranspiration, to the extent that rainfall amount exceeds potential evapotranspiration only in a very few and scattered days (Hatibu *et al*, 2000).

There are districts in Ethiopia where long-term average rainfall is more than 900 mm per annum yet crop production is very low. This is because of poor distribution rainfall leads to water stress of plants during one or more stage of growth. Consequently, the plants may use all rainwater but still produce low yield, especially if water stress occurs during a critical growth stage. Thus, the productivity of rainfall, land and inputs become very low. As a result, the country has been affected by recurrent drought and famine for many years.

Irrigation development is an important means for achieving food self-sufficiency and food security in many arid and semi arid countries, including Ethiopia, in order to address the main challenge caused by food insecurity. Accordingly, agricultural development through irrigation has been a priority for the new Ethiopian government since its establishment in 1991 so as to increase food production and achieve food self- sufficiency for the rapid increasing population (WIC, 2000).

It is evident that irrigation continues to play major role in poverty alleviation by providing food security, protection against famine, expanded employment opportunities. Ethiopia has about 3.6

million ha potentially irrigable land with surface water, though only 189,556 ha,(about 5 % of the potential) is to date utilized (Hillel, 1997 cited in Sijali, 2001).

The Tigray region is one of the most degraded and drought prone regions of Ethiopia. The total area of the region is approximately 80,000 km^2 and situated in the mountainous northeast of the country; altitude ranges between less than 500 to over 3000 m a.s.l (REST, 2002). There are 35 woredas in Tigray region, of which, 621,000 households (75% of a total population of four million) is food insecure (BoNAR, 2003) and seriously threatened by droughts. Most part of the region receives inadequate annual rainfall for economic dry farming production. The timing of precipitation in these areas is erratic and most of this limited rainfall comes in sporadic, intense and unpredictable storm usually on crusted soils with low infiltration rate resulting in surface runoff uncontrolled rill and gully flow. Generally the major climatic limitations for agricultural production are erratic rainfall, often combined with intermittent dry spells that regularly threaten the survival of annual and perennial crops.

The Regional Bureau of Water Resource Development estimates that "Tigray can potentially irrigate 50,000 ha, using various water management schemes" (Co water international, 2003). Micro and medium sized dams, river diversions, groundwater exploitation, pumped irrigation and at present the favored choice ponds and shallow wells. The target for the fiscal year 2003 was to construct 40,000 ponds, 80% made with plastic lining (geo-membrane), the remaining with clay lining. Of the targeted only 30,588 were built (BoANR, 2004). The target for the fiscal year 2004 was 160,000, 60% with plastic lining, of only 23,311 were built up to July, 2004 (BoANR, 2004). Most of the constructed ponds in the region have a total water holding capacity of 191 m^3 each and designed to supplement from 0.01 ha up to 0.1ha of land based on the water requirement of different crops up to end of October (RWRB and REST 2003).

1.1 Statement of the problem

Household pond construction has been the major rainwater harvesting technology in Tigray, since 2003. Even though the constrictions of ponds have a significant contribution in terms of alleviating poverty, the adoption rate is very slow, in terms of constructing new ponds as well as on utilizing the stored water in the existing ponds. Besides, the productivity of ponds is not evaluated well prior to large-scale intervention in the region. Here, the main objectives of the ponds were to provide supplementary irrigation for staples crops in farm fields; however, according to BoANR (2003 and 2004) few beneficiaries applying it practically. On the other hand, considerable number of farmers is currently utilizing for homegardens. Furthermore, the common design of ponds (Trapezoidal) was not the preference of most farmers. According to farmers the main reasons specified are: the ponds occupy large area of land for construction and they are exposed to high evaporation and seepage losses. Accordingly, the expansion of ponds is becoming controversial issue.

Generally, in order to keep the permanence of household ponds in the region, the following research questions should be addressed with scientific methodology. Those are: the contribution of household pond on the expansion of homegardens, the actual water productivity of ponds and the problems in relation to pond design and approach.

1.2 Purpose of the study

This study would then attempt to indicate the impacts of household ponds on the development of homegardens by quantifying the economic and physical water productivities of household ponds. The outputs of this study could be applicable for further effective implementation of small-scale water harvesting activities in the region; besides, it clearly indicates the strong integration of homegarden and water harvesting.

1.3 Hypothesis of the Study

Household pond construction could have a great contribution on the expansion of homegarden in Tigray. On the other hand, there would be inefficient utilization of pond water hence; the water productivity of existing ponds could be less as compared to designed potential productivity of ponds.

1.4 Objectives of the study

The goal of this study is to assess the role of household ponds on the expansion of homegarden. The specific, objectives of this study are:

- To analyze farmers perception towards the construction of water harvesting structures for developing homegardens.
- To quantify the impact of household ponds on tree survival and growth.

- To analyze the water productivity of household ponds in terms of economic and gross production
- To sort out the problem faced in the expansion of homestead tree plantation and to recommend possible solutions.

Chapter II: Literature review

2.1 Introduction

Homegarden practice consists of diverse mixture of vegetables, fruits, medicinal plants and other fodder grasses, shrubs or trees in small intensively cultivated plots in and around home compounds (Rocheleau *et al.*1988).

According to the working manual developed by REST (1997), home compounds and adjacent fields are considered to be private land, and should not be threatened by reallocation, and therefore they are the most secured. The result is that most of the private plantations are on home compound sites, practical reason such as ease of tending, may contribute to this pattern, but the principal reason is security of tenure. The evidence suggested that people are very willing to plant trees and look after them and even pay for them in some cases, if they feel secure.

Furthermore, homestead plantation is an important source of household income. Homegardens contribution to the well being of rural households is often under estimated by outsiders. However, both formal surveys and informal reports indicate that rural people are keenly interested on planting trees around their houses and compounds (Rocheleau *et al.*, 1988). As indicated in the same source homegardens are best suited in densely populated areas where land is in short supply. This case demonstrates that farmers may be motivated to adopt and develop multistory production system in homegardens. Besides homegardens may be managed by either sex, women most often manage them. And they provide a legitimate place for women to cultivate agricultural crop since they are usually located close to the home compounds. They are also ideal sites for introducing soil and water conservation measures.

2.2 Experiences in homegarden

The concept of homestead development is simple and very essential for semi-arid and arid areas of Ethiopia. Based on this concept some encouraging activities have been implemented as a model in some parts of Ethiopia, which is conducted by the Ministry of Agriculture. According to Betru (2001), the primary objectives of the project are to identify the problems on homestead and requirements of household. Following this the major components would be implemented on the homestead according to farmer's requirements. The components include: live fencing, improved cropping practices, improved soil management practices, soil and water conservation, water harvesting techniques, horticultural development, animal husbandry, poultry, apiculture and home economics.

After one-year of implementation period of the national project service unit of Ministry of Agriculture had been evaluated, the main lessons learnt from this intervention are indicated as; (1) The adoption of water harvesting activity encouraged farmers to diversify their products and generate better income from small plots and intensification and diversification of activities a valid opportunity of proper use of family labour; (2) Allocation of land for productive ventures enabled generation of better income and the income generated from sales of vegetables enabled farmers to cover school fees and the vegetable provided the family with alternative means of balancing their diet.

In Tigray also similar pilot trials have been undertaken on homegarden. According to REST annual report (2002), in eight program areas of REST, 21 ponds were constructed. After two year a study was carried out to evaluate the effectiveness of the ponds. Accordingly, 14 ponds (67%) were efficiently utilized, while and 33% were inefficient due to certain reasons such as seepage loss, low motivation and awareness of farmers.

Although the constructed ponds had small capacity (22.5m^3), they provided considerable support for irrigating tree seedlings and vegetables planted in their backyard. The ponds were served minimum of one week and maximum of five months during of August to January. The frequency of watering was ranging from 2 to 25 times a season. For instance in Wukro district farmers were watering their vegetables and trees every two days starting from August 2002 up to January 2002.

According to the same report, the watering effort has great effect on the survival rate and growth of the planted seedlings at household level. Seedlings that were watered have got high survival rate, i.e around 100% as compared to seedlings that did not get water from ponds. (Table 1 below presents the survival rate of trees in the back yard of on farmer near Wukro town)

Table 1**.** Planted tree species Vs their survival rate

S/N	**Species**	**Planted**	**Survived**	**%**
1	Papaya	10	6	60
2	Orange (sweet)	2	2	100
3	Guava	10	10	100
4	Coffee	5	5	100
	Total	27	23	85

Source: REST (2003),

Further more, in Muaquar area of Jordan (mean annual rainfall of 125mm), small farm ponds were able to collect water every year with sufficient amount to justify profitable agricultural development (Oweis and Jaimer, 1996 as cited in Kijne et al 2003). In Mehasseh Steppes of Syria (120mm annual rainfall) rain-fed shrubs had less than 10% survival rate, while those grown under micro-catchment had an over 90% survival, shrub survival rate can be improved from 10 to 90% with the introduction of water harvesting intervention even during 3 drought year, after one relatively normal year (Oweis and Jaimer, 1996 as cited in Kijne et al 2003). As indicated in the same source, in North West Egypt (130mm annual rainfall), small water harvesting basins with 200 m^2 catchment support Olive trees and rainwater from the roofs of green houses provide about 50% of the water required by the vegetable grown with in them. These experience and many others show that productivity of rain in dryer environments can be substantially increased when a proper water harvesting technique is implemented.

2.3 Accounting for water use and productivity

Water accounting is a procedure for analyzing the use depletion, and productivity of water in a water basin context. It is a supporting methodology useful in assessing impact of field level agricultural intervention and performance of irrigation agriculture. The water accounting methodology is based on water balance approach. The water balance considers inflows and outflows from the basin, sub basins, and service and use levels such as irrigation systems or fields (Molden, 1997).

Water accounting integrates the following water balance components:-

- *Gross inflow* is a total amount of water flowing into the domain from precipitation and surface and sub surface sources
- *Net inflow* is the gross inflow plus any change in storage.
- *Water depletion* is a use of removal of water from the water basin that reduces unavailable for further use. It encompasses evaporation, flows to sinks (deep percolation), pollution and incorporation to product.

Table 2. Water accounting components at field and service level of irrigation

Field level	**Irrigation service**
In flow	
• Irrigation application • Precipitation • Subsurface contribution • Surface seepage flow	• Surface diversions • Precipitation • Subsurface sources • Surface drainage sources
Storage change	
• Soil moisture change in active root zone	• Soil moisture change • Reservoir storage change • Ground water storage change

Process depletion	
• Evaporation from soil surface, including fallow lands • Weed evaptranspiration • Lateral or vertical flow to salt sinks • Flow to sink • Water rendered unusable due to degradation of quality	• Evaporation from free water and soil surface, weeds, phreatophytes, and other non crop plants • Flow to sinks • Evaporation from ponds/playas • Water rendered unusable due to degradation of quality
Out flow	
• Deep percolation • Seepage • Surface runoff	• In stream commitment such as environmental and fisheries. • Down stream commitment • For municipal and industrial use with in irrigation service • Uncommitted out flow

Source: Molden, 1997

2.4 <u>Water use performance indicators</u>

The development of performance benchmarks to evaluate the commercial benefits of irrigation should include not only an assessment of irrigation and drainage volumes but also the crop yields, water costs and enterprise returns (Skewes and Meissner, 1998, cited in Raine,1999). Some examples of water use efficiency indices are provided in Table 3.

Table 3. Examples of water use efficiency indices for the evaluation of irrigation performance

Terms	Definitions
Gross Production Water Use Index	*Total Product (kg)* / *Total Water Applied (ML)*
Irrigation Water Use Index	*Total Product (kg)* / *Irrigation Water Applied (ML)*
Marginal Irrigation Water Use Index	*Marginal Production due to irrigation (kg)* / *Irrigation Water Applied (ML)*
Crop Water Use Index	*Production (kg)* / *Evapotranspiration (mm)*
Gross Production Economic Water Use Index	*Economic return ($)* / *Total Water Applied (ML)*
Irrigation Economic Water Use Index	*Economic return ($)* / *Total Irrigation Water Applied (ML)*
Marginal Irrigation Economic Water Use Index	*Marginal return due to irrigation ($)* / *Irrigation Water Applied (ML)*
Crop Economic Water Use Index	*Economic Return ($)* / *Evapotranspiration (mm)*

Source : Raine,1999.

Performance indicators for water accounting follow depleted fraction and effective efficiency concepts presented by Willardson, *et al*. (1994) and Keller and Keller (1995) cited in Molden (1997). Water accounting performance indicators are presented in the form of fractions, and in terms of productivity of water.

Depleted Fraction (DF) is that part of the inflow that is depleted by both process and non-process uses. Depleted fraction can be defined in terms of net, gross, and available water (Willardson, *et al*. 1994)

$$DF_{net} = \frac{Depletion}{Net\ Flow} \qquad (1)$$

$$DF_{gross} = \frac{Depletion}{Gross\ Flow} \qquad (2)$$

$$DF_{available} = \frac{Depletion}{Available\ Water} \qquad (3)$$

Process Fraction (PF) relates process depletion to either total depletion or the amount of available water.

$$PF_{depleted} = \frac{Process\ Depletion}{Total\ Depletion} \qquad (4)$$

$$PF_{depleted} = \frac{Process\ Depletion}{Available\ Water} \qquad (5)$$

2.5 Productivity of water in agriculture

A study was conducted by Mintesinot *et al* (2004), on assessment of water productivity under irrigation and rain fed agriculture for major crops grown in Tekeze river basin, Tigray, Ethiopia (Mintesinot *et al*.2004). This study reveals that, the water productivity under irrigation condition was highest for potato followed by onion and maize (1.84, 1.07, and 0.23 kg/m^3, respectively). Whereas, rainfall water productivity was highest for wheat followed by maize and teff (0.37, 0.28, and 0.18 kg/m^3 respectively). In general the water productivity assessment show that the productivity of diverted water is less than crop water requirement, which is an indication of inefficient water management.

On another study, Mintesinot *et al*, (2005) found economic productivity of diverted water was highest for onion (0.29 USD/m^3), followed by potato, (0.24 USD/m^3) and maize had the lowest, which was 0.08 USD/m^3.

2.6 Raising water productivity

There are many ways of raising irrigation water productivity, a few standouts. For those using surface irrigation, reducing seepage from the canals used to carry water from large reservoirs to farms cuts water use. A second approach is to use more efficient technology such as overland sprinklers system and drip irrigation. The conjunctive use of rainfall and irrigation water also enhances water productivity (Kijne et al, 2003). The average rainwater productivity for wheat grain in the dry areas is about 0.35 kg/m^3 (Kijne *et al*, 2003). However, this may increase to as much as 1.0 kg/m^3 with improved management and favorable rainfall distribution. It was found that 1 m^3 of water applied as supplementary irrigation at the proper time might produce more than 2 kg of wheat grain over that using only rainfall, (Kijne *et al*, 2003). The detail result is indicated in the table below.

Table 4. Rain water productivity (WP_R), combined rain and irrigation (SI) water productivity (WP_{R+I}) and irrigation- water productivity (WP_I) of bread wheat grain in Northern Syria.

Year	**Rain (mm)**	**WP_R (Kg/m^3)**	**SI (mm)**	**WP_{R+I} (Kg/m^3)**	**WP_I (Kg/m^3)**
1991/92	351	1.04	165	1.16	1.46
1992/93	287	0.7	203	1.23	2.12
1993/94	358	1.08	175	1.17	1.43
1994/95	318	1.09	238	1.08	1.06
1995/96	395	0.91	100	0.90	0.73
Mean WP		**0.96**		**1.11**	**1.73**

Source -Kijne et al, 2003

Chapter III: Materials and methods

3.1 Site selection and description

3.1.1 Locations

The research area distinctively comprises three woredas (districts), in Tigray Regional State, namely Hintalo Wajerate, Kilte Awulaelo and Atsbi wonberta. The study areas were selected based on the intensive water harvesting activities implemented and the proximity to close investigation.

Hintalo Wajerate is geographically located between 39^0 30’ E - 39^0 45’ E and 13^0 00’N - 13^0 15’ N at An average distance of 35 km from Mekelle. It borders with Afar region in the east Samre Seharti and Alaje woredas in the west, Raya Azebo in the south and Mekelle in the north. The district encompasses a total of 19 Tabias and 77 Kushets .

Kilte Awulaelo district is geographically located between 39^0 30’ E - 39^0 45’ E and 13^0 45’ N - 14^0 00’ N located in the eastern part of Tigray at a distance of 45 km from Mekelle, It borders with Howzien and Sease Tsadamba in the north, Atsbi Womberta in the east, Douga Tembien in the west and Mekelle in the South. The woreda currently encompasses a total of 15 Tabias and 64 Kushets.

Atsbi Wonberta woreda is geographically located between 39^0 30’ E - 39^0 45’ E and 13^0 30’ N- 13^0 45’ N located in eastern Zone of Tigray about 75 km northeast of Mekelle.

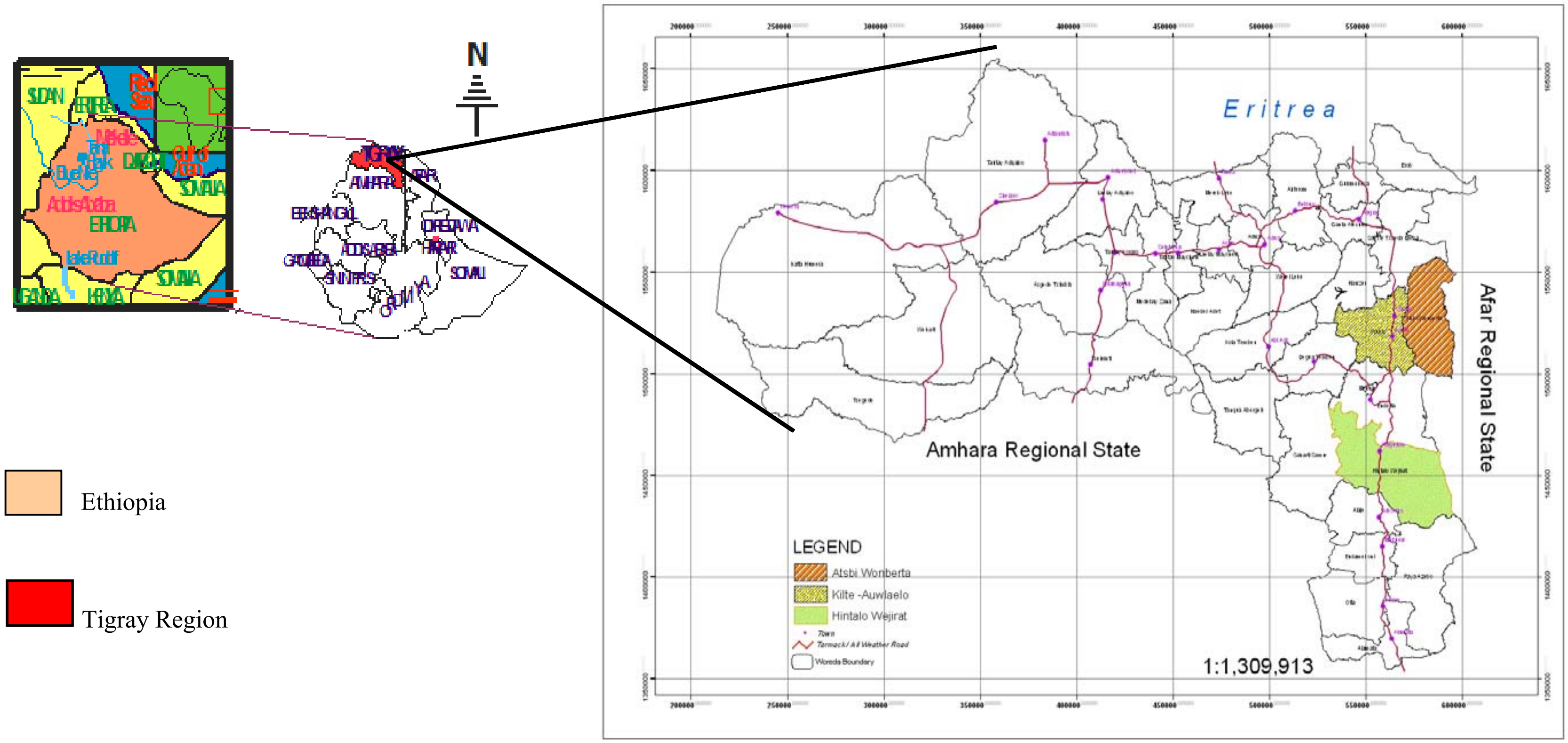


Figure 1. Location of the study areas

3.1.2 Climate

The agro-climatic zone of Hintalo Wajerate is classified in to three main climatic zones. These are low land, mid land and high land. Each constitutes 23.68%, 68.42% and 17.90% of the total area coverage respectively. The altitude of the woreda is ranging from 1400 m to 2250 m a.s.l. The average daily air temperature of the area ranges between 15 ^{0}C and 30 ^{0}C. The mean annual rainfall of the area is about 470 mm.

Kilite Awulaelo woreda is classified in to three main agro-climatic zones. These are 15% Douga, 82% Wina Douga and 3% kola agro-climatic zone. The altitude of the woreda ranges from 1980 m to 2500 m a.s.l. The average daily air temperature of the area ranges between 15 ^{0}C and 30 ^{0}C. The mean annual rainfall of the area is about 558 mm.

The altitudes of Atsbi Wonberta woreda ranges from 1500 m to 2800 m a.s.l. The average daily air temperature of the area ranges between 15 ^{0}C and 30 ^{0}C. The mean annual rainfall of the area is about 529 mm.

The study woredas are considered drought prone, as the rainfall is very erratic. Ten out of the twelve months a year the potential evapotranspiration is much higher than the long-term average rainfall (Co water international, 2003a). Besides the availability of adequate reliable moisture in June (on set season) for germination and September (offset season) for the flowering and fruiting process is crucial pre requisite for crop production as well as tree growth (Co water international, 2003a).

3.1.3 Population

According to the population census carried out in 1994, the total population of Hintalo Wajerate woreda is about 119,196; Out of which 49.36% is male and 50.64% is female. The total number of household heads is 24,145 and average family size is 5 (BoANR, 2004).

The total population of Kilite Awlaelo woreda is about 106,733; Out of which 51,767 is male and 54,966 is female. The total number of household's head is 22,780 and average family size is 5 (BoANR, 2004).

The total population in Atsbi Wonberta on the other hand, is 80,107; out of which 37,697 is male and 42,410 is female. The total number of household heads is 19,432 and the average family size is 5 (BoANR, 2004).

3.1.4 Description of household water harvesting ponds

Catchments, a small pond and a command area characterize the individual household pond. All are managed at household level. The great advantage of this storage system is the relatively simple social operation and maintenance structure in relation to communal ponds. Water is directly harvested by runoff or taken from a gully or stream with a diversion structure and stored in a pond to be used when required (TRWB and REST, 2003).

According to Co water international report (2003a), the earth household ponds are improved dug out ponds, which have been developed by the Tigray Regional Water Resource Bureau and Relief Society of Tigray (REST). They have trapezoidal cross section with internal slope of between 1.5

to 1 and 2 to 1 and the capacity generally varies between 81 and 191 m^3. Most of the ponds are approximately 13 by 13 m. However, there are also ponds with different sizes: 12 m by 12 m, 10 m by 10 m and 8 m by 8 m with stepped side (Table 5 presents different size of ponds and their construction cost). In some cases, where the local soils are highly permeable, the ponds are lined with plastic and cement (Figure 2 presents ponds with different lining). The ponds usually have complementary structures such as silt trap, feeder canals, and access stairs but often do not have a spillway. Water lifting is done by bucket. Some of the ponds are fenced with variety of materials but most are not. The system is fed with water from the nearby micro catchments (Table 6 presents area to be irrigated with 109 m^3 pond).

Table 5. Comparative cost of ponds

Compacted clay lined water harvesting ponds

Pond size	Stored volume (m^3)	Grain in kg	Cash Equv.(ETB)	Cash (ETB)	Total cash cost (ETB)	Total cost per water stored(ETB/m^3)
8mx8m	81.25	1256	3139	500	3639	44.79
10mx10m	131.25	1930	4825	500	5325	40.57
12mx12m	191.25	2681	6704	500	7204	37.67

Source, Landell Mills,2004

Plastic lined water harvesting ponds

Pond size	Stored volume(m^3)	Grain in kg	Cash Equv.(ETB)	Cash(ETB)	Total cash cost (ETB)	Total cost per water stored(ETB/m^3)
8mx8m	81.25	1140	2851	1289	4140	50.95
10mx10m	131.25	1749	4372	1661	6033	45.96
12mx12m	191.25	2427	6066	2032	8098	42.34

Source, Landell Mills,2004

Table 6. Estimated area to be irrigated by a pond having $109m^3$ capacity

S/N	Crop	Irrigation plot (M^2)	Yield (qt/ha)	Yield (qt/plot)	Unit price (birr/Qt)	Total price (birr)
1	Onion	177.47	100	1.78	250	445
2	Pepper (green)	228.61	100	2.29	350	801.5
3	Pepper (dry)	228.61	12	0.35	1500	525
4	Tomato	98.20	300	2.95	100	295
5	Potato	173.3	200	3.47	200	694
6	Maize	950.07	40	3.8	200	760
7	Sweet potato	283.69	300	8.51	250	2127.5
8	Cumine	275.62	20	0.55	500	275
9	Millet	1013.2	15	1.52	200	304
10	Bean	286.4	70	2.010	220	442.2
11	Sorgum	1331	40	5.32	200	1064
12	Carrot	217.2	150	3.26	125	407.5
13	Cabbage	217.2	200	4.34	150	651
14	Barely	661.3	20	1.32	180	264
15	Wheat	661.3	20	1.32	200	264

Source, RWRBT and REST,(2003)

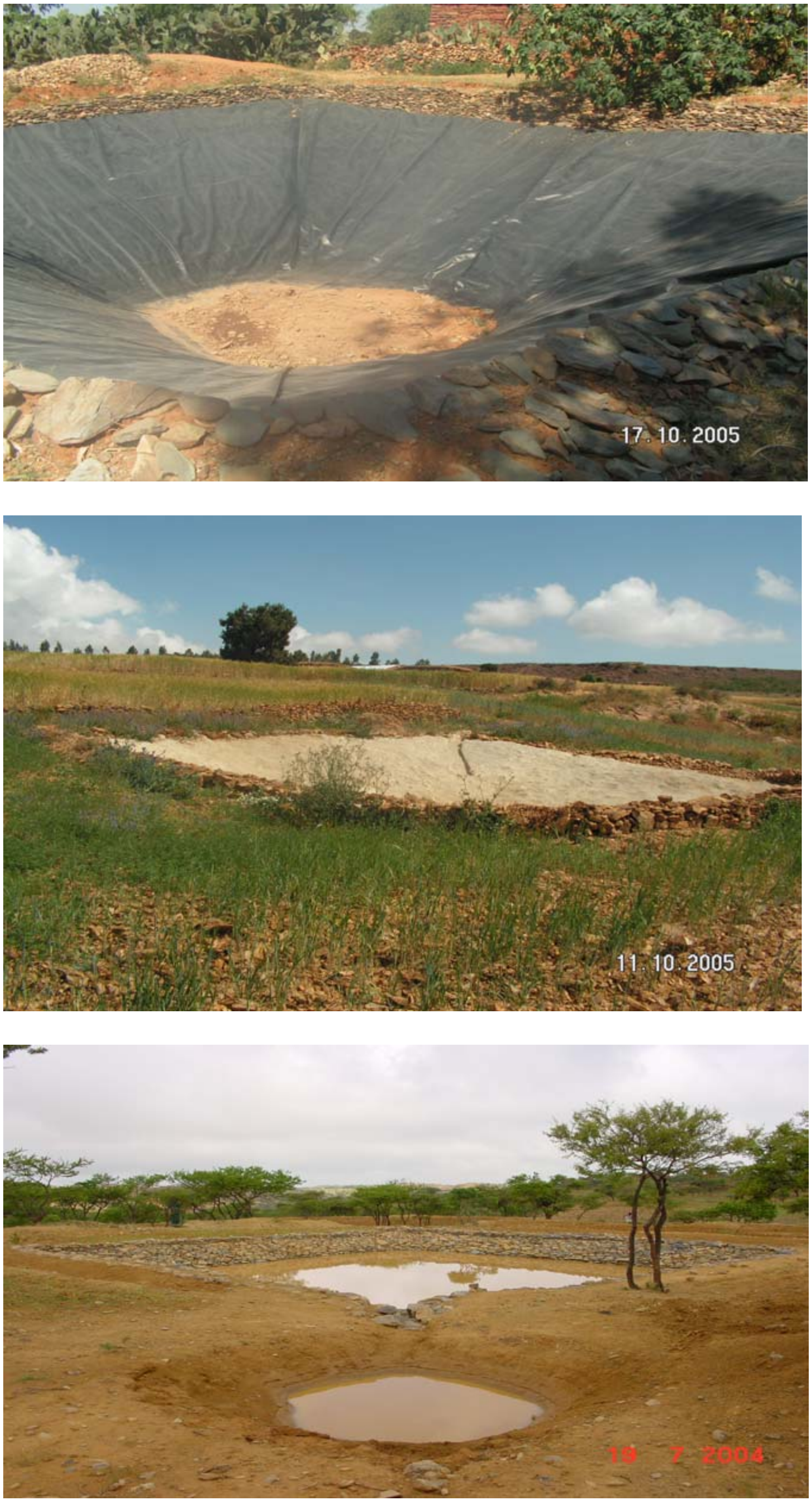


Figure 2. Types of pond lining (Plastic, cement and clay lined ponds respectively

Geometry of ponds: In Tigray region trapezoidal ponds were common design, however in limited sites cylindrical ponds were also constructed by non-governmental organizations. Figure 3 presents the designs of trapezoidal as well as cylindrical ponds.

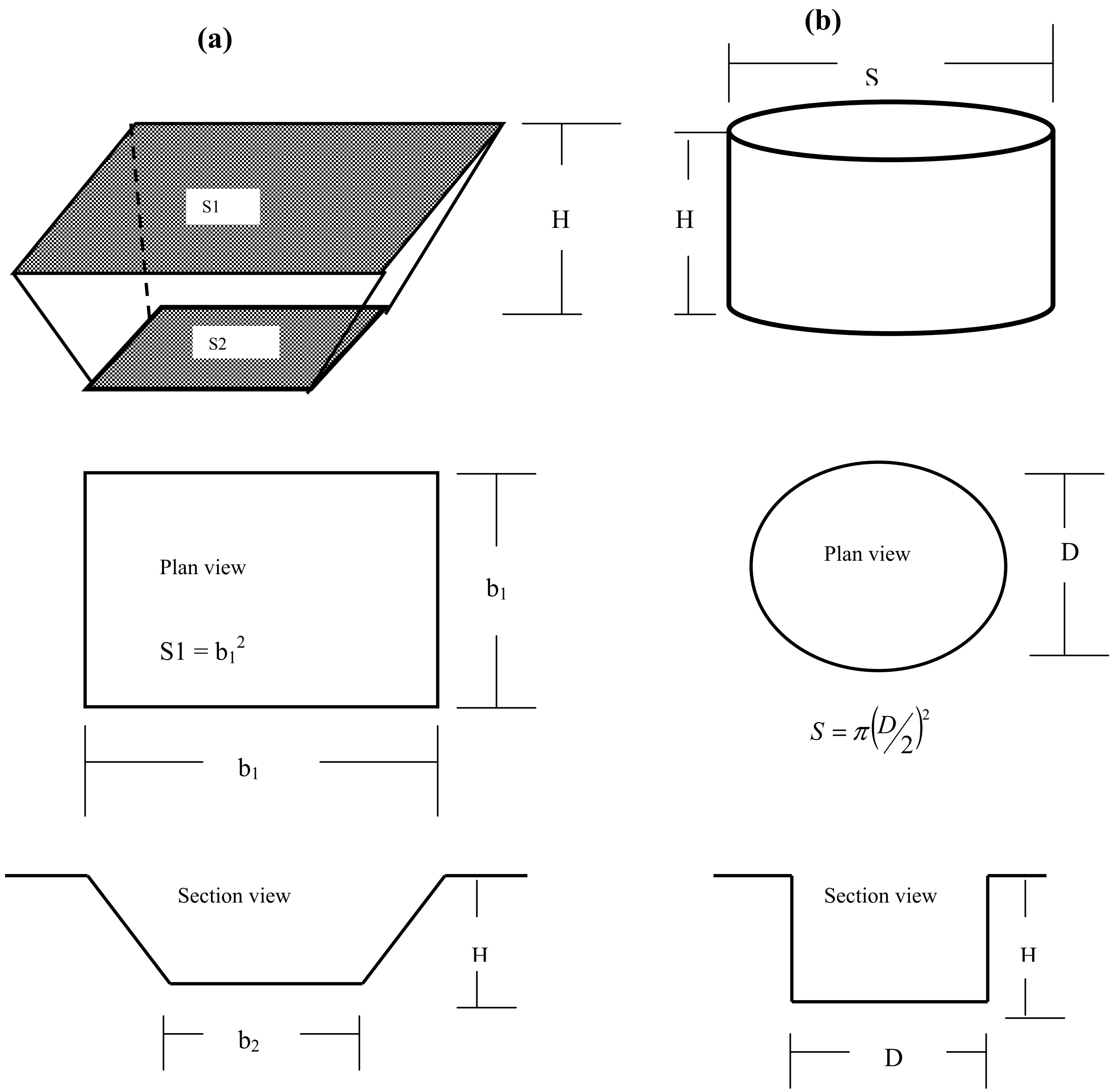


Figure 3. Geometry, shape, dimension and volume of trapezoidal (a) and cylindrical (b) pond

Formula for calculating the volume of trapizoidal versus cylindrical ponds respectively

$$W_{in} = \left(H/3\right) \times \left(S1 + S2 + \sqrt{S1 \times S2}\right) \qquad W_{in} = \pi\left(D/2\right)^2 \times H \qquad (6)$$

Where: W_{in} is volume of the pond, S1 is top area of the pond, S2 is bottom area of the pond, H is depth of the pond

According to BoANR annual report (2003), in the target woredas (Kilte Awulaelo, Hintalo Wajerate and Atsbi Wonberta) a total of 4,395 household ponds were constructed. Out of which 1,593 ponds were filled with water and stayed up to end of November (Table 7 presents the status of constructed ponds in the targeted Woredas). Most beneficiary households utilized the pond water for supplementing homegardens such as vegetables, spices, fruit and forage trees. A total of 90.3 ha of vegetable and spice and 13,147 newly planted tree seedlings have been irrigated for some months of the dry season. The planted tree species includes Orange, Papaya, Guava, Sesbania sesban , Leucaena lecocephala , Rhumnus spp., and Coffea arebica. On the other hand, vegetables such as tomato, potato, cabbage and onion were also irrigation. However, in the target woredas few farmers only had supplemented their cereal cropland despite the fact; the primary objectives of the constructed pond were to provide irrigation for cereal crops.

Table 7. Performance of household ponds in the target woredas; (Ponds constructed in 2003)

Woreda	**Constructed ponds in 2003**			**Pond filled with water**			**Ponds, which had been utilized by the beneficiaries.**
	Plastic lined	Clay lined	Total	Plastic lined	Clay lined	Total	
Hintalo wajerate	1059	1391	2450	453	576	1029	1003
Kilte Awlaelo	587	1658	1945	287	277	564	564
Atsbi Womberta	174	1935	2109	32	318	350	350
Total	**1820**	**4984**	**6504**	**772**	**1171**	**1943**	**1917**

Source: - BoANR ,2003.

Table 8**.** Total irrigated land with the constructed household ponds in fiscal year 2003

Woreda	**Size of irrigated land with constructed ponds (supplementary irrigation)**		
	Vegetables and spices in ha	**Cereals in ha**	**Tree in number**
Hintalo wajerate	39.5	0	7440
Kilite Awlaelo	50.8	0	5707
Atsbi wonberta	48.8	0	15,000
Total	**139.1**		**28,147**

Source: BoANR, 2003.

3.2 Sampling procedure

The method used for selecting households for socioeconomic survey and water productivity analysis is purposive sampling. The total number of households selected for socioeconomic survey and for the assessment of tree growth and survival count was 60, which consisted of 30 pond owners and the remaining with out ponds. Accordingly, 20 farmers were considered from each of the targeted woredas (Hintalo Wajerate, Atsbi Wonberta and Kilte Awlaelo). Out of the total sample 75 % were male headed where as the rest were female-headed households. 55 % of the targeted household heads were illiterate and 68% of the household heads were categorized in the age of 36 – 55 years.

Table 9. Selected sample households for the study

Woreda	**Tabia**	**Total constructed household ponds**	**Ponds under utilization**	**Sample households with ponds**	**Sample households with out ponds**
Hintalo wajerate	May Nebri	76	45	10	10
Kilte Awlaelo	Abrah Atsbha	161	25	10	10
Atsbi womberta	Hayelom	213	43	10	10
Total				**30**	**30**

Besides, six ponds were selected for detailed investigation of water productivity, which encompass two ponds from each targeted woredas (districts). Out of the selected six ponds five of them were plastic lined and the remaining one pond was clay lined. All of the ponds were located in the backyard, so farmers were using them for the production of vegetables and fruit trees.

3.3 Data collection procedure

A thirty two-question survey was administered and tree performance indicators were collected. The data collection includes: type of planted tree species, source of seedling, planting date, tree inventories (survival rate), diversity of trees, and frequency of species and dominancy of species. Moreover, tree growth indicators such as stem diameter were measured.

- Inventory of trees in the garden were conducted with the total count of trees survived at the end of 2004 rainy season. Moreover the plantation data were collected from the surveyed households (30 with pond and 30 without pond).
- Tree stem diameters were measured slightly above the root collar with caliper gauge. Accordingly, the diameters of dominant trees in the garden were measured from the studied homegardens (30 with pond and 30 without pond) (Durvea, M.L.1985).

Furthermore, assessment of pond type and capacity; the status of homegarden, measurement of irrigated plot size, types of vegetables and spices or other herbs were conducted. Besides, location of the garden, the cropping pattern, daily water utilization and depth of the pond water were identified and measured. Secondary data such as Meteorology data, potential crop yield for common vegetable species and market price of each vegetable spices, were collected.

3.4 Method of data analysis

The Statistical Program for Social Sciences, version 10.0,(SPSS,2002) was used to analyze the socio economic as well as tree survival and growth situation.

The water productivity analysis was conducted by the water balance accounting approach (Molden, 1997) and (Hatibu *et, 1997*). Water balance considers the inflow and outflow from the reservoir. Water balance equation assumes inflows are equal to outflows plus any change of storage within the domain. Moreover, the water productivity of household ponds was evaluated by using irrigation performance indicators (Raine,1999). Accordingly, estimating each component of the water balance model (water balance of the pond) was determined. Moreover, Cropwat 4 Window Ver 4.3 (FAO, 1998) was used to estimate the potential evapotranspiration and the crop water requirements of each vegetable plot.

The water balance model of the pond: The model derived from the equation of water going through individual sequence by the following general hydrological equation (Hatibu *et al*, 2000);

$$\boxed{\Delta W = I_a - O} \qquad (7)$$

Where:

I_a = inflow of water to a given area during a given time period.

O = Outflow of water from the area during the same period

ΔW = Change in storage of the volume in the area during the time period.

In the case of water harvesting ponds, at the end of the rainy season the ponds harvest their maximum holding capacity (W_{in}), which is equivalent to total inflow of water (I_a); the out flow components are evaporation loss (E_{vol}), gross application of water for irrigation (IRR_{v+t}), seepage loss ($Q_{seepage}$), Livestock water use (LV) and the pond volume occupied by silted material (Q_{silt}) and soil moisture available in the silted material ($Q_{soil\ moist}$); ΔW is equivalent to the water remained excess in the pond after the growing season.

Based on the above explanation, the water balance equation of the pond is explained as follow.

$$\boxed{W_{in} - IRR_{v+t} - LV - E_{vol} - Q_{seepage} - Q_{silt} - Q_{soil\ moist} = 0} \qquad (8)$$

Where:

W_{in} = total amount of water harvested by the pond in m^3;

IRR_{v+t} = Gross supplementary irrigation amount in m^3;

LV = Water utilized for livestock watering in $m^{3;}$

E_{vol} = evaporation loss from the pond surface in m^3;

Q_{silt} = the pond volume occupied by silted material in m^3;

$Q_{soil\ moist}$= Soil moisture hold in the silted material in m^3; and

$Q_{seepage}$ = estimated seepage loss in m^3.

Water use efficiency indicators for the evaluation of irrigation performance : To evaluate the irrigation performance of the system, gross production water use index and gross production economic water use index were used. The total production from each irrigation plot and the total water applied in system (effective rain fall and gross supplementary irrigation amount) were directly measured during the period of field assessment. Finally, the results were compared with the maximum potential yield amount obtained from each plot.

$$\textbf{Gross production water use index} = \frac{Total\ production(Kg)}{Total\ Water\ Applied(m^3)} \qquad (9)$$

$$\textbf{Gross Production economic water use} = \frac{Economic\ return(birr)}{Total\ Water\ Applied(m^3)} \qquad (10)$$

3.4.1 Methods used to determine water balance components

For this particular case, the components of water balance are: Effective rain fall, Actual evapotranspiration, Gross amount of supplementary irrigation, Soil moisture change, evaporation loss, seepage loss, surface run off, and volume of pond occupied by silted material, livestock water use.

Moreover, to determine the crop water requirement of each vegetable plots with Cropwat model, the following in put data were determined: The climatic input data required are reference evapotranspiration (monthly/decade) and rainfall (monthly/decade/daily). Reference evapotranspiration was calculated from actual temperature, humidity, sunshine/radiation and wind-speed data, according to the FAO Penman-Monteith method (FAO, 1998). Other input data such as available soil moisture content, Soil texture class, Maximum rain infiltration rate, Maximum rooting depth, Initial soil moisture depletion, planting date, crop type and percentage area covered by particular crop.

To determine the above components, the following detail procedures were employed:

Climatic data : Most of the metrological data except precipitation were collected from Mekelle Air port station, which is the only class one metrological station, found near the study sites. Temperature, sunshine hour, relative humidity, wind speed and precipitation were collected for the year 1954 to 2004. The temperature data was adjusted with altitude difference of the sites to the nearby meteorological station.

By using the above input data potential evapotranspiration, effective rainfall and solar radiation were computed with help of Cropwat software, version 4.3 (FAO, 1998). In Appendix A, the collected mean monthly meteorological data is stated. Moreover, the graphical representation of long term mean annul rainfall and potential evapotranspiraion is explained below. The graphs in Fig 4,5 and 6 indicate clearly that the amount of precipitation exceeds PET only in the two months of July and August in ayear.

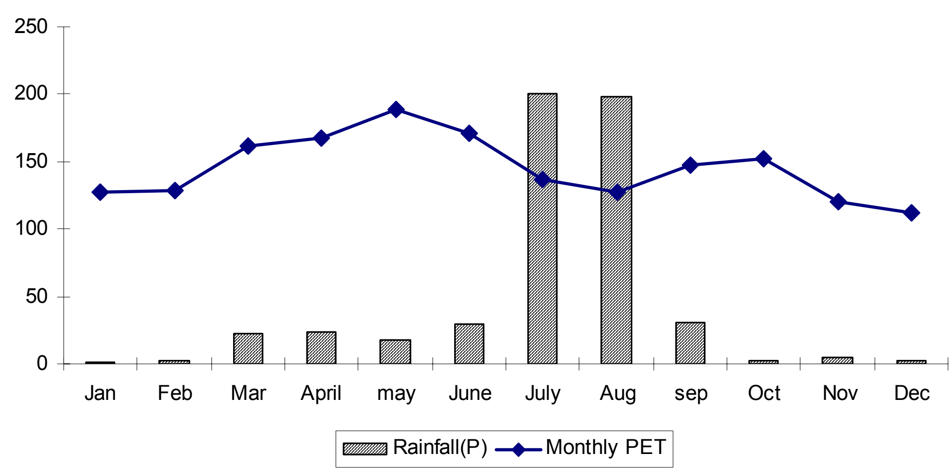


Figure 4. Mean monthly rainfall, Potential evapotranspiration (1959-2004) for Kilte awlaelo woreda

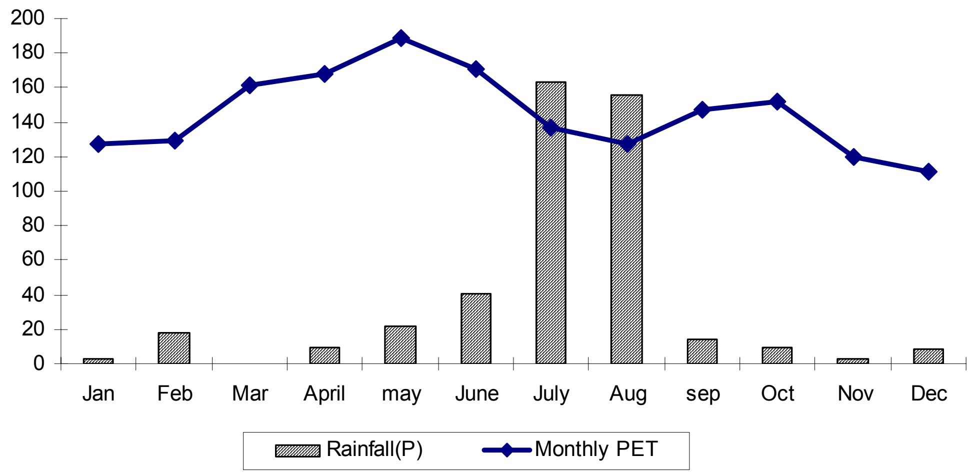


Figure 5. Mean monthly rainfall, Potential evapotranspiration (1959-2004) for Haykemeshal(Atsbi Wonberta woreda)

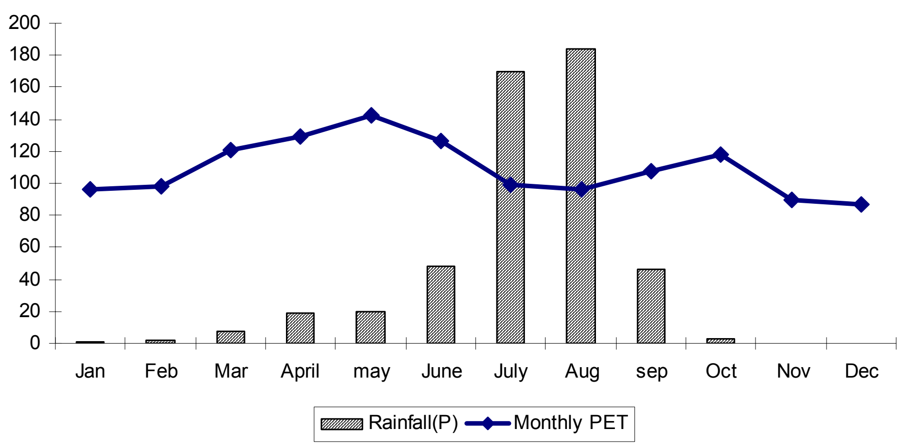


Figure 6. Mean monthly rainfall, Potential evapotranspiration (1959-2004) for Hintalo Wajerate woreda.

Potential evapotranspiration :It was computed by modified Penman -Monteinth equation (with Cropwat for windows software, version 4.3 (FAO, 1998)). The FAO Penman-Monteith method is recommended as the sole method for determining ETo. The method has been selected because it closely approximates grass ETo at the location evaluated, is physically based, and explicitly incorporates both phisiological and aerodynamic parameters. The input data required were monthly mean wind speed, sunshine hour, temperature (minimum and maximum) and humidity.

Effective rainfall: It was also computed by Cropwat for window , version 4.2 (FAO,1998). Effective rainfall is a function of gauge Rainfall and Interception. The input data of the software is monthly mean rainfall; hence, the output data is monthly effective rainfall.

Evaporation from the pond water surface: In the study areas pan evaporation data was not available. So Penman (combination) method was used to determine the evaporation loss from the pond surfaces (Shaw, 1994). It was developed to calculate open water evaporation based on fundamental physical principles with empirical concepts incorporated to enable standard meteorological observations to be used from the standard meteorological tables developed by FAO (FAO, 1998).The penman formula for open water evaporation is given by

$$Eo = \frac{\Delta/\gamma\,(H) + Ea}{\Delta/\gamma + 1} \qquad (11)$$

Where Eo = open water evaporation in mm/day;

H = the available heat in mm/day;

Δ/γ = Weighting factor (a function of temperature); and

Ea = to be determined empherically (mm/day).

The above formula requires the value of H and Ea as well as Δ/γ for its application in the open water evaporation from the ponds. H is calculated from incoming radiation (Ri) and out going radiation (Ro) determined from sunshine records, temperature and relative humidity using

$$H = R_1(1-r) - R_o \tag{12}$$

Where r is albedo and equals 0.05 for water, R_1 is a function of Ra and radiation is given by $R_1(1\text{-}r)=0.95Ra(0.18+0.55\ n/N)$. (13)

n is sunshine hour, N is mean daily duration maximum possible sunshine hour, which is dependant on latitude.

Ra and N are obtained from standard meteorological table (Appendix 2a).

The term Ro in the equation is given by

$$Ro = \delta Ta^4(0.56 + 0.09\sqrt{ed}(0.1 + 0.9\, n/N) \tag{14}$$

Where δ is Stephan – Boltzman constant 5.67 x 10^{-8} w/m^2k^4 and temperature must be converted in to Keliven.

The value of δTa^4 (mm of water) is given in Appendix 4a (FAO,1998).

Next Ea in equation 11 is found by the coefficients derived by experiment for open water.

$$E_a = 0.35(0.5 + \frac{U_2}{100})(e_a - e_d) \tag{15}$$

Where U_2 is mean wind speed at 2mm above the surface in mile/day;

e_a is saturated vapor pressure at air temperature Ta;

e_d is vapor pressure of the air;

$(e_a\text{-}e_d)$ is saturated deficit.

Finally Δ/γ is weighting factor (a function of temperature) and it is tabulated in Appendix 4c (FAO, 1998).

The detail analysis of evaporation is explained in Appendix C

Analysis of the actual pond water utilization : For estimating the pond water utilization amount; water application amount and the pond water level were recorded in three-day interval from the six ponds, which have been selected for the water productivity study. The water utilized for irrigating trees (IRR_t) and vegetables (IRR_v), water used for domestic (Q_d) and livestock (LV) were also recorded separately on the prepared format. Moreover, for measuring the water level of the pond graduated rope hanged on the tip of long pole was used. Based on the data collected with the above method, the amount of water utilized for each purpose was estimated.

Figure 7. During measurement of the pond water depth (Haykemeshal)

The water is commonly utilized by the households for supplementary irrigation of vegetables and trees in the garden. Besides some households were using the water for livestock and domestic uses. The utilized amount by each targeted households for particular purpose had been recorded with three days interval (Appendix E). The irrigation application methods for most of them were spot irrigation by using Buckets. According to the findings of this study, most of the pond water was utilized for irrigating trees (Table 10), as compared to other uses.

Table 10. Depth of supplementary irrigation water in the study homegardens

Description	LK	AT	HA	SW	HB	HM
Duration of supplementary Irrigation	Sep. 6/04- Jan 9/05	Sep.9/04 - Jan 24/05	Sep 15/04- Jan21/05	Sep14/04- Dec.28	Sep2/04 - Jan 2/05	Sep4/04 - Jan 10/05
Total Vegetable plot size in M^2	402.00	185.00	257.00	707.00	332.00	206.00
Gross water application for veg. In M^3 (IRRv)	42.24	62.28	57.11	57.51	25.44	26.59
Gross Irr. Depth (IRR_v) in mm	**105.09**	**336.64**	**222.22**	**70.32**	**76.63**	**104.69**
Size of the garden occupied by trees m^2	44.00	39.00	44.80	20.30	37.00	30.42
No of trees in the garden	56	50	56	26	47	39
Gross water application for trees. In M^3 (IRRt)	59.14	77.49	76.15	55.14	36.63	33.68
Gross Irr. Depth (IRR_t) in mm	**1478.56**	**2039.17**	**1699.78**	**2716.26**	**990.11**	**1107.22**

Analysis of the pond volume occupied by silted material(Q_{silt}):The silt accumulation in the pond was directly measured after the pond had been emptied. The volume of precipitated silt was estimated by conducting direct measurement.

Analysis of the moisture content in the silted material ($Q_{soil\ moist}$): The soil moisture available in the silted material was estimated from the moisture holding capacity of the soil at saturation point. It is computed from soil moisture analysis by sand box and pressure plate apparatuses in the lab. (Appendix F).

Analysis of the seepage loss ($Q_{seepage}$): Most of the selected ponds for water productivity are plastic lined because the clay-lined ponds had already lost their water by seepage in the fist week of September. Due to this one clay-lined pond was considered for seepage study.

In the clay-lined pond, the seepage loss was estimated from the water balance equation of the pond, which is described below.

$$Q_{seepage} = W_{in} - IRR_t - IRR_v - LV - E_{vol} - Q_{silt} - Q_{soil\ moist} \quad (16)$$

Where

W_{in} =Total amount of water in m^3 which was harvested by the pond;

LV= Amount of water utilization for livestock (m^3);

IRR_t = Supplementary water amount in m^3/m^2 per growing season applied for the trees in the garden;

IRR_v = Supplementary water amount in m^3/m^2 per growing season applied for the vegetable plots;

E_{vol} = Evaporation loss in m^3/m^2 from the pond surface;

Q_{silt} = Pond volume in m^3 occupied by silted material;

$Q_{soil\ moist}$= Soil moisture in the silted material in m^3; and

$Q_{seepage}$ = Estimated seepage loss in m^3.

3.4.2 Method of computing crop water requirement (CWR)

Required water for particular crop within the full plant growth was calculated using Cropwat for windows version 4.2 (FAO, 1998). CROPWAT is a computer program for irrigation planning and management, developed by the Land and Water Development Division of FAO (FAO, 1998). Its basic functions include the calculation of reference evapotranspiration, crop water requirements, and crop and scheme irrigation.

The required input data are monthly precipitation amount in the main rainy season of the year (June, July, August & September), planting date, crop type, and percentage of plot size, which is covered by particular crop.

$$\boxed{CWR = PET * Kc * Area\ planted} \quad (17)$$

Where, PET is Potential Evpotranspiration

CWR is Crop Water Requirement

Kc is crop coefficient

The considered climatic data as input for the software were monthly evapotranspiration and monthly rainfall amount. More over, soil data such as total available water content (TAW) in mm, soil texture class, maximum infiltration (in mm/day), maximum rooting depth in mm (Z_e), and initial soil moisture depletion (RAM) were considered.

The Output of the Cropwat software were total water required for each crop on monthly bases and amount of water actually supplied by rainfall; and amount of supplementary irrigation required per ten days irrigation interval.

Soil particle size distribution: Pipette method was used to determine the particle size distribution of the soil. The samples were taken from the profile pit excavated in the homegardens. The soil samples were dried and crushed, and then it was passed through 2 mm sieve. Accordingly, the soil particle having a diameter less than 2mm was separated. Through chemical attack (acid/base and redox) cementation agent was removed, and with the use of charged ions dispersed clay particles was forced, the separated particle move down word with constant sedimentation velocity that obeys the formula of stocks (Landon, 1990).

This makes it possible to calculate exactly the depth at which a specific fraction can be present at a given time; the fraction was characterized by a specific spherical diameter. Therefore the crushed soil samples where analyzed by pipette method and finally the percentage composition of sand (2mm -0.05mm), silt (0.05mm-0.002mm) and clay (<0.002mm) was determined. The soil texture class was obtained from the texture triangle on the bases of the percentage composition of sand, silt and clay.

The particle size of the soil was determined by pipette method in the laboratory of Land resource Management and Environmental Protection Department of Mekelle University. About 24 soil samples were taken from the pond command area, four samples from each profile.

Figure 8**.** Excavated profile pit for soil sample collection (Abrha Atsbha and Maynebri)

Table 11. Soil particle size distribution of the study site

Sample code	Depth	Sand (%)	Silt (%)	Clay (%)	Texture class
HA1	0-15cm	5.7	5.5	88.8	*Clay*
HA2	15-45cm	12.7	8.4	79.0	*Clay*
HA3	45-100cm	7.8	4.6	87.6	*Clay*
HA4	>100cm	10.3	8.3	81.4	*Clay*
SW1	0-15cm	30.4	33.1	36.5	*Clay loam*
SW2	15-45cm	39.9	32.8	27.3	*Clay loam*
SW3	45-100cm	43.8	27.7	28.6	*Clay loam*
SW4	>100cm	27.3	45.9	26.8	*Loam*
LK1	0-15cm	87.4	4.7	7.9	*Sand*
LK2	15-45cm	90.7	6.6	2.7	*Sand*
LK3	45-100cm	82.9	14.2	2.9	*Loamy sand*
LK4	>100cm	80.7	8.3	11.0	*Loamy sand*
HM1	0-15cm	20.6	59.9	19.6	*Silt loam*
HM2	15-45cm	7.9	68.1	24.0	*Silt loam*
HM3	45-100cm	3.2	4.7	92.1	*Clay*
HM4	>100cm	26.9	57.5	15.7	*Silt loam*
HB1	0-15cm	50.0	33.3	16.7	*Sandy loam*
HB2	15-45cm	39.3	40.4	20.3	*Loam*
HB3	45-100cm	44.8	40.9	14.4	*Loam*
HB4	>100cm	40.2	44.1	15.7	*Loam*
AT1	0-15cm	71.4	6.8	21.9	*Sandy clay loam*
AT2	15-45cm	76.6	7.1	16.4	*Sandy loam*
AT3	45-100cm	83.6	10.8	5.6	*Loamy sand*
AT4	>100cm	76.1	14.9	9.0	*Sandy loam*

Maximum rain infiltration rate (mm/day): The maximum rain infiltration rate of the pond command area was estimated from the relation of soil infiltration rate and texture, which is given in booker tropical soil manual (Landon, 1990).

Maximum rooting depth and other properties of the soil: The maximum rooting depth was estimated from the six profile pits, which were excavated in the targeted pond command areas.

Based on the observation conducted in the field, maximum rooting depth (Z_e) of 100cm was taken for most of the sites. Other important properties of the soil were determined in the field and given in Appendix D.

Total available water (TAW) : TAW is defined as the volume of water retained between field capacity (FC) and permanent wilting point (WP). TAW is the amount of water that a crop can extract from its root zone and its magnitude depends on the type of soil and rooting depth (FAO, 1998).

$$\boxed{TAW = (1000(\theta_{fc} - \theta_{wp}) \times Z_e} \qquad (18)$$

Where

TAW = the total available soil water in the root zone (mm);

θ_{fc} =moisture content at field capacity (m^3m^{-3});

θ_{wp} = moisture content at wilting point (m^3 m^{-3}); and

Z_e = rooting depth (m).

For the determination of soil characteristics curve, 15 undisturbed samples were taken from six profile pits using core samples. Care was taken, during sampling in order to take only 100cm^3 to make accurate calculation of volumetric moisture content and bulk density. After saturation cores were put on the sand box and exposed to suction level of 0 up to 100cm (pF =2).

For the determination of suctions higher than 1 bar, disturbed samples were used. The disturbed samples were put on pressure plates (wetted ceramics) and exposed to high pressure up to 15 bar (which is almost wilting point). The moisture loss of each suction level was calculated using

$$\rho_b = \frac{W_c - W_{rtr}}{V_c} \tag{19}$$

$$\theta_v = \frac{W_c - W_d}{V_c} \tag{20}$$

$$\theta_m = \frac{M_{tinwet} - M_{sdry}}{M_{tindry} - M_{tin}} \tag{21}$$

$$\theta_w = \theta_m \times \rho_b \tag{22}$$

Where ρ_b =bulk density; θ_v = volumetric moisture content;

W_c=mass of dry core; θ_m = Gravimetric moisture content;

W_d= mass of core oven dry; M_{tinwet}= Mass of tin with wet soil;

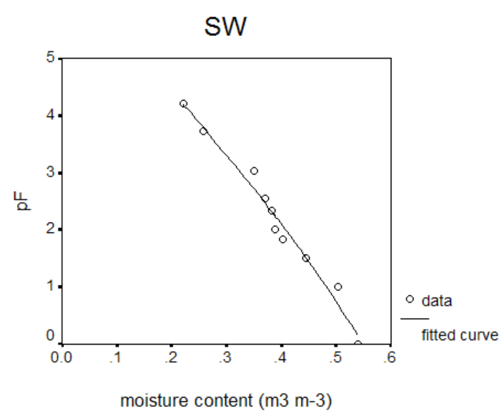
V_c= volume of core; M_{tindry}= mass of tin of dry soil; and

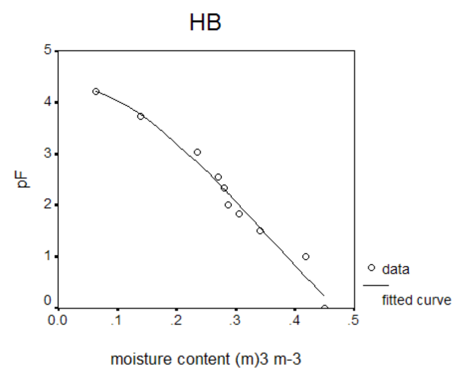
M_{sdry}= mass of dry soil; M_{tin}= mass of tin

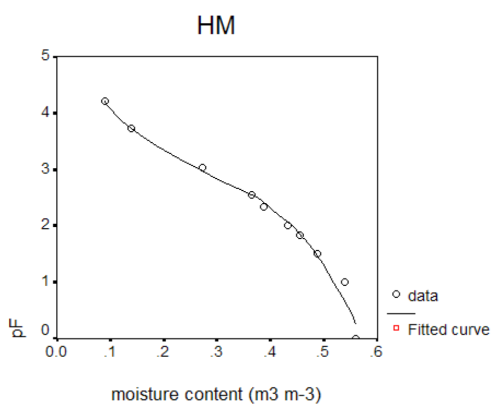
W_{rtr}= mass of ring, tissue & rubber ring;

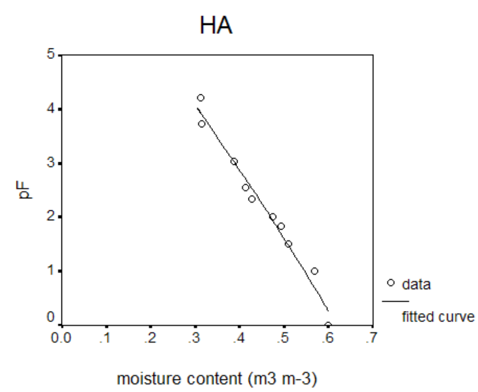
Table 12. Estimated TAW and FC of the soil in the command areas of six ponds

HH cod	θ_{fc} (m^3m^{-3})	θ_{WP} (m^3m^{-3})	Ze In m	$TAW = 1000(\theta_{FC} - \theta_{wp}) * Ze$	$FC = \theta_{fc} * Ze * 1000$
AT	0.17	0.08	1	90	170
LK	0.09	0.04	1	50	90
HA	0.51	0.31	1	200	510
HM	0.43	0.09	1	340	430
HB	0.29	0.06	1	230	290
SW	0.43	0.22	1	210	430









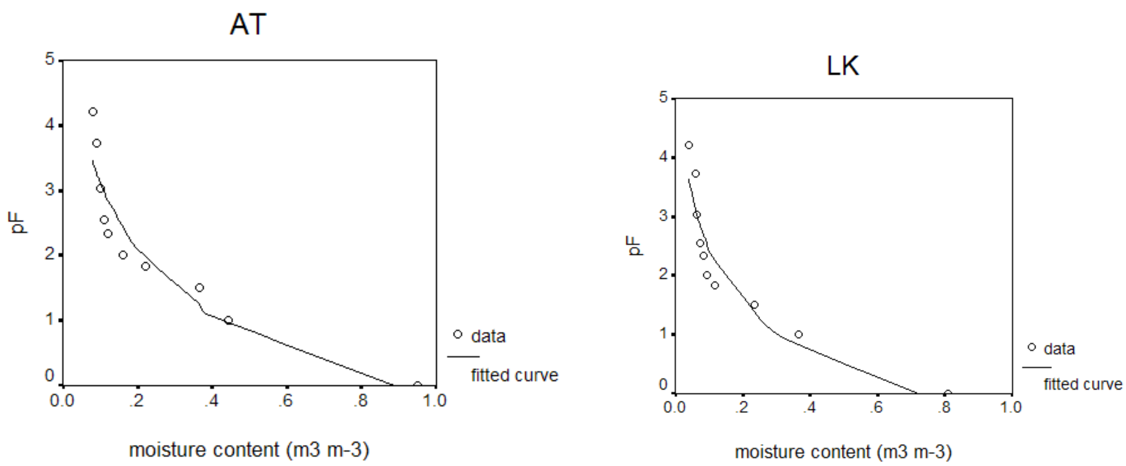


Figure 9. Soil moisture characteristic curve of the studied back yards

Initial soil moisture depletion (RAW) :Initial soil moisture depletion or readily available water (RAW) is the fraction of TAW that a crop can extract from the root zone with out suffering water stress (FAO,1998).

$$RAW = p * TAW \tag{23}$$

Where, TAW = the total available soil water in the root zone (mm);

RAW = the readily available soil moisture in the root zone (mm)

p= average fraction of TAW that can be depleted from the root zone before moisture stress, the factor p differs from one crop to another. It varies from 0.3 for shallow rooted plants to 0.7 for deep-rooted plants. Generally a value of 0.5 for p is commonly used for many crops.

The determined values of RAW were explained in table 13 below

Plant type, planting calendar and percentage area coverage by the specific crop : Most of the annual crops planted in the garden were vegetables and spices. The common vegetable species observed were green pepper, tomato, swiss chared, cabbage, potato, sweet potato, onion, carrot and lettuce. All the data related to crop is described briefly in Appendix G.

Table 13. Summarized soil input data for crop water requirement estimation

Soil input data	**AT**	**LK**	**HM**	**HA**	**HB**	**SW**
Total Available Water (TAW) in mm	90	50	200	340	230	210
Texture class	Sandy loam	Sand	Silt loam	Clay	Loam	Clay loam
Max Rain infiltration rate (mm/day)	3.33	10.42	0.83	0.33	0.83	0.63
Max rooting depth(Z_e) in mm	1000	1000	1000	1000	1000	1000
Initial soil moisture depletion (RAW) = p*TAW in mm	24	24	150	58.5	108.5	79.5

Chapter IV: Results and discussion

4.1 Farmers perception towards the utilization of water harvesting ponds for homegardens

The result of socio economic survey indicated that: About 96.6% of the respondents had started homegarden after the introduction of household ponds, where as the rest have pervious experience in backyard vegetable production. Furthermore about 40% of the respondents mentioned moisture stress as the main reason among other constraints indicated in Table 14 for not to plant trees on their backyard before the intervention.

On the other hand, almost 100% of the respondents have already understood the significance of water harvesting for increasing the survival rate of trees; moreover, the availability of water in the pond initiated them to plant more trees and vegetables in their backyard.

Table 14**.** Main reason for not to plant trees in their backyard

Description	**Frequency**	**Percent**
Land shortage	8	26.6
Lack of money	1	3.4
Labor scarcity	1	3.4
Moisture stress	12	40
Tenure insecurity	1	3.4
Lack of tree seedling	3	10
Damage by livestock (free grazing)	4	13.4
Total	**30**	**100**

In the assessment, 100% of the respondents proffered the location of the pond to be on their backyard for better utilization. Among the surveyed households, there was no interested respondent to excavate household ponds on the farm. Their main reason was ponds far from homestead are very difficult to protect and guard the site from livestock damage. However, based on the data obtained from regional BoARD (2004), more than 60 % of the ponds, which had been constructed in 2003 and 2004 fiscal year, were located on farmland, which are relatively far from their home. Even though those ponds had water, the utilization was very limited when compared to ponds, which have been constructed in the backyard

Generally this finding indicated that the better location of household pond should be near homestead. Because ponds, which have been constructed in the backyard, are easy for protection and management such as cleaning silt trap and control of excess runoff. Besides, it could be a good opportunity for women to participate in horticultural activities for generating better income.

4.2 The impact of household ponds on tree survival, growth and diversity

Based on the assessment conducted in the studied backyards, trees, which received supplementary irrigation, showed significant difference in survival and growth when compared to trees planted by pond less farmers. For this comparison two-year plantation and survival inventory data were taken (fiscal year 2003 and 2004) and direct measurement of tree collar diameter was conducted for selected trees in the garden. Therefore, the average survival rate of trees (Figure 11) with ponds was 84% where as it was 69 % with out ponds (usually farmers irrigate their trees by fetching water from nearby rivers and water points). The mean stem diameter of trees (Figure 10) with ponds was 2.2 cm where as without ponds were 1.8 cm. The mean diversity of trees in the garden with access for supplementary irrigation was 4.4 whereas it was 3.32 in pond less gardens. Common tree species planted in the observed backyards were *Citrus sinesis, Cirus medica, Citrus reticulate, Mangifera indica, Psidium guajava, Persea*

Americana, Rhmnus prinodies, Catha edulis, Papaya, Banana, Sesbanea sesban, Leucaena leucocephala, Eucalphtus Spp. and Coffee tree.

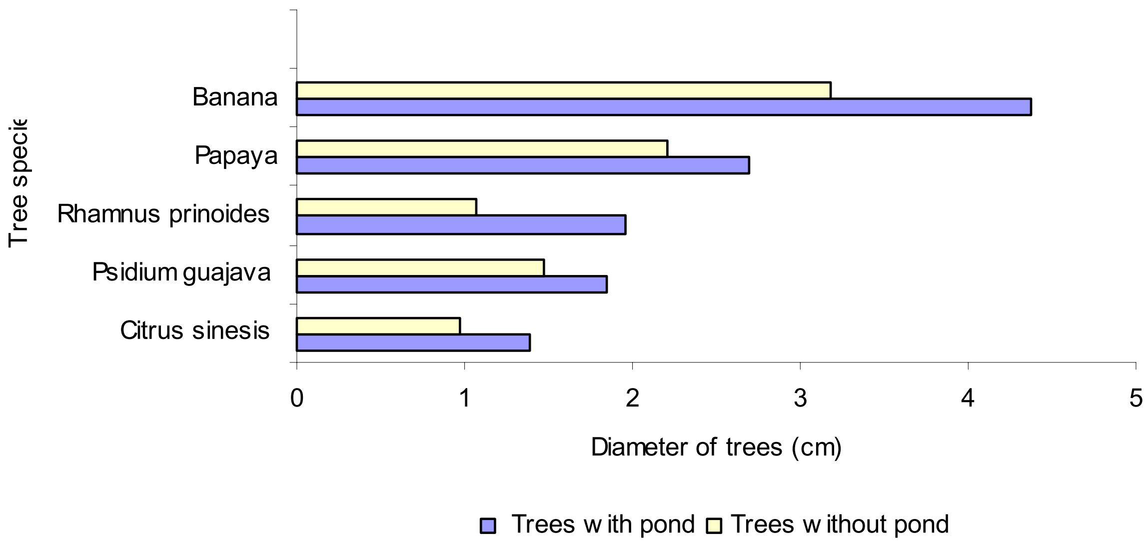


Figure 10. Mean comparison of tree diameter for different trees with and without pond

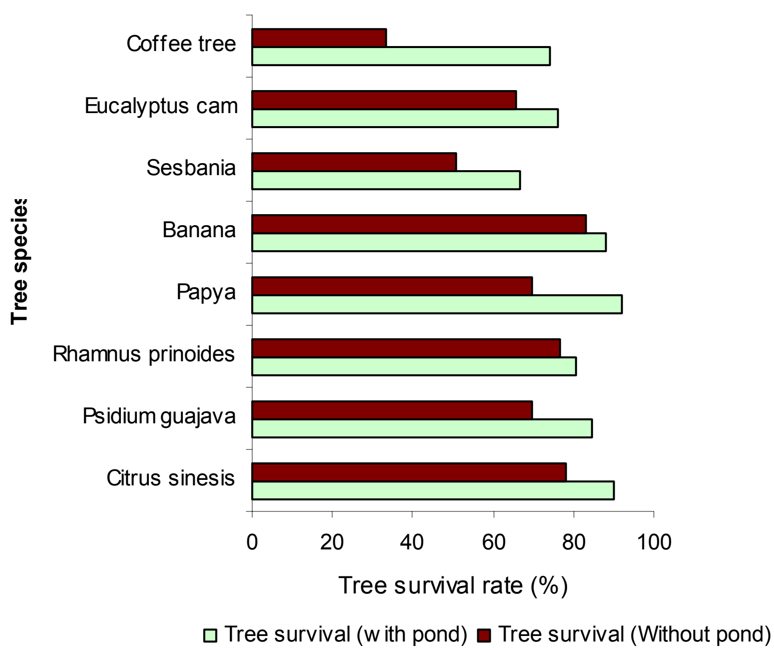


Figure 11. Mean comparison of tree survival rate for different trees with and without pond

Table 15. Mean diversity of tree species on HH having ponds and without ponds

Description	**Mean**	**N**	**Std. Deviation**
Trees species diversity with pond	4.40	30	2.44
Trees species diversity without pond	3.23	30	1.38
Total	**3.82**	**60**	**2.05**

Table 16. One-way ANOVA test for diversity of tree species in pond command areas Vs in backyard plantation with out pond

Source of variability	**Sum of Squares**	**Df**	**Mean Square**	**F**	**Sig.**
Between Groups	20.417	1	20.417	5.181	.027
Within Groups	228.567	58	3.941		
Total	**248.983**	**59**			

Figure 12. Well-grown fruit in the homegarden (Haykemesehal)

Based on the result obtained, the survival rate of trees in the irrigated areas of homegarden (84%) had showed a better result when compared to homegardens with out pond. This implied that the availability of supplementary irrigation in the backyard has significant contribution on the survival of trees (fruit trees) in the homegarden. Besides, based on tree stem diameter result comparison, trees, which had access for supplementary irrigation, were thicker in diameter than trees with out supplementary irrigation. Fore instance *Citrus sinesis*, *Papaya, Banana* and *Rhamnus prinoides* had more than 40% diameter difference. The diversity of trees was analyzed by descriptive statistics and one-way ANOVA test. Accordingly, the diversity of planted trees in the backyard of pond owners' versus farmers with out pond showed a significant difference at 0.05 levels; besides, the mean diversity of tree species for pond owners exceeded by 36 %. (Table 15 and 16 presents the analysis in detail).

The above results showed that tree survival, growth and diversity were improved because of the availability of supplementary irrigation in the backyard. In other words it is an indication that household pond construction had a significant contribution for the expansion of homestead agro forestry in the region.

4.3 Contribution of water harvesting ponds for household income

In the study area, three-years household income data (2002, 2003 and 2004) were considered. Fiscal year 2002 income of household was taken to compare the pond impact in the following two years (2003 and 2004). The income of the targeted households had shown a significant change after the intervention of household ponds (Table 17). Generally speaking after the construction of household ponds about 4% mean income increment had been recorded. In the analysis of household income the value of tree products was not included, because some trees give production after three years.

Table 17. Income change due to the intervention of household pond

	INC1994	**INC1995**	**INC1996**
N	30	30	30
Mean income (ETB)	1778.83	1789.37	1843.69

4.4 Accounting of water use at pond level

In the accounting of pond water balance, it was found that more water was used for irrigating trees than vegetables, moreover, the seepage loss was high for clay compacted ponds and the evaporation loss is critical for all type of ponds.

Evaporation loss: The results of evaporation estimation in table 23 explains that, a minimum of 17.03 m^3 and maximum of 29.1 m^3 water was directly lost from the pond surface. As compared to other pond designs, the average evaporation loss obtained from trapezoidal pond was 37% larger than cylindrical pond having the same capacity. Although the designer did not consider the evaporation loss was a big issue, it is still significant.

Figure 13. Trapezoidal shaped plastic lined pond with high evaporation surface and Cylindrical shaped pond with low evaporation surface area.

Table 18 .The summery of estimated evaporation loss (September to December)

Name of the pond owners	Estimated Evaporation loss (m^3)
AT	23.8
LK	22.3
HA	17.35
SW	20.78
HB	29.1
HM	26.43
Mean	**23.3**

Seepage loss: Seepage loss from ponds is one of the critical issues identified in the assessment. Hence, from clay compacted pond (Table 24), the seepage loss was about 40 m^3, which was very high when compared to other losses. On the other hand, the seepage loss from plastic lined ponds was insignificant. Here the seepage loss could be high on the damaged plastic lined ponds. Generally, the clay compacted ponds were inefficient in preventing seepage, thereby threatening the success of the water harvesting scheme. The main reasons which clay lined ponds associated with higher seepage as compared to plastic lined ones are:

poor compaction, inadequate thickness of clay material, lack of understanding on the conditions in which clay lined ponds are preferred.

Accumulation of silted material: As shown in the result (Table 24) below, significant amount of siltation was not observed on the evaluated ponds, but in the long term regular maintenance and clearing of the silt trap should be carried out.

Table 19. Calculated water balance of the pond

Components	**AT Amount in M^3**	**LK Amount in M^3**	**HA Amount in M^3**	**SW Amount in M^3**	**HM Amount in M^3**	**HB Amount in M^3**
IRR_t	77.49	59.14	76.15	55.14	33.68	36.6
IRR_v	62.28	42.24	57.11	57.51	26.59	25.44
LV	0	27.03	0	55.07	7.09	16.28
E_{vol}	23.8	22.3	17.35	20.78	26.43	29.1
$Q_{seepage}$	0	0	0	40.16	0	0
W_{in}	195.35	207.3	151.3	229.5	189	185.68
Q_{silt}			0.441	0.51		
$Q_{soil\ moisture}$			0.26	0.28		
W_r	31.78	56.59	0	0	95.21	78.26
Water balance of the pond ($W_{in}=IRR_t+IRR_v+LV+Q_{silt}+Q_{soil\ moist}+E_{vol}+Q_{seepage}+W_r$)	0	0	0	0	0	0

Based on the analysis and the results indicated above, the water utilization was estimated from the pond water balance model. Accordingly, 30% was utilized for supplementing trees in the garden; 24% for supplementing vegetable plots; 10% for livestock watering, and about 34% of the water in the pond was remained excess for the next round irrigation. On the other hand, the estimated average losses were 12% by evaporation and 17.5 % by seepage (for clay lined ponds only). 0.26% of the pond volume was occupied by silt. From the above water balance components, the amount of water used for supplementing trees is more than the water used for supplementing vegetable plots. Relatively less amount of water were utilized by households for livestock watering because they are prioritizing for irrigation of horticultural trees.

4.5 Gross production water use

Table 25 -30 below has shown the water productivity of actually applied supplementary irrigation versus the computed amount of supplementary irrigation in vegetable and spices on the command areas of the assessed six ponds.

In the result indicated on Table 25, the actual supplementary water for the green pepper plot was 522.2 mm and the computed water requirement was 652.39 mm with actual yield of 0.55 kg/m^2 and 1.5 kg/m^2 respectively, and the resulted crop water productivity of actually supplied water was 1.05 kg/m^3 whereas the computed was 2.30 kg/m^3. Therefore, 0.95 kg of additional Green pepper could be obtained with effective water utilization. Table 26 indicated that with one-meter cub of supplementary water the actual obtained yield of cabbage was 2.84 kg as compared to computed amount which is 7.79 kg per one cubic meter supplementary irrigation.

Generally, the computed water productivity was observed to be much greater than the actual water supplied. For instance about 75 % additional yield could be obtained for green pepper and onion crops as compared to tomato crop, which had up to 83 %, yield increment obtained by using the effective water application method.

Figure 14. Homegarden near the pond in Haykemesehal

Table 20. The results of water productivity analysis for vegetable crops (For HA pond).

Crop type	[1]R+SI (mm)	[2]R+SIc (mm)	Yield (Kg/m^2)	[3]MPY (kg/m^2)	Crop water productivity (kg/m^3)	
					[4]WP_{R+SI} (Kg/m^3)	[5]WP_{R+SIc} (Kg/m^3
Green Pepper	522.20	652.39	0.55	1.5	1.05	2.30
Onion	521.60	341.34	0.95	1	1.83	2.93
Potato	505.40	360.42	2.86	4	5.65	11.10

Table 21. The results of water productivity analysis for vegetable crops (For LK pond).

Crop type	R+SI (mm)	R+SIc (mm)	Yield (Kg/m^2)	MPY (kg/m^2)	Crop water productivity (kg/m^3)	
					WP_{R+SI} (Kg/m^3)	WP_{R+SIc} (Kg/m^3)
Cabbage	491.6	449.42	1.40	3.5	2.84	7.79
Tomato	492	544.44	0.10	1.5	0.20	2.76
Swiss chared	474.5	409.40	0.80	1	1.69	2.44
Lettuce	474.5	434.48	0.74	1.5	1.56	3.45
Carrot	474.5	423.30	0.84	1	1.77	2.36
White cumin	491	418.48	0.40	0.8	0.81	1.91
Black cumin	491	422.57	0.40	0.8	0.81	1.89

Table 22.The results of water productivity analysis for vegetable crops (For HB pond).

Crop type	R+SI (mm)	R+SIc (mm)	Yield (Kg/m^2)	MPY (kg/m^2)	Crop water productivity (kg/m^3)	
					WP_{R+SI} (Kg/m^3)	WP_{R+Sic} (Kg/m^3)
Tomato	406.00	459.95	0.83	1.5	2.04	3.26
Green Pepper	415.00	592.80	0.02	1.5	0.05	2.53
Cucumber	388.00	377.68	5.00	6	12.887	15.88

[1] R+SI = Rainfall plus actual Supplementary irrigation
[2] R+SIc= Rainfall plus Computed supplementary irrigation
[3] MPY = Maximum potential yield
[4] WP_{R+SI} = Water productivity of rainfall plus supplementary irrigation
[5] WP_{R+SIc} = water productivity of rainfall plus computed supplementary irrigation

Table 23.The results of water productivity analysis for vegetable crops (For SW pond)

Crop type	**R+SI (mm)**	**R+SIc (mm)**	**Yield (Kg/m^2)**	**MPY (kg/m^2)**	**Crop water productivity (kg/ m^3)**	
					WP_{R+SI} (Kg/m^3)	**WP_{R+Sic} (Kg/m^3)**
Cabbage	476.12	342.83	1.52	3.5	3.18	10.21
Green Pepper	478.00	397.60	0.06	1.5	0.13	3.77
Onion	476.00	335.09	0.50	1	1.05	2.98
Sweet potato	479.00	381.08	1.11	1	2.32	2.62
Potato	470.00	358.30	0.09	4	0.20	11.16
White cumin	476.00	419.55	0.20	0.8	0.42	1.91
Black cumin	476.00	427.79	0.19	0.8	0.39	1.87

Table 24. The results of water productivity analysis for vegetable crops (For AT pond).

Crop type	**R+SI (mm)**	**R+SIc (mm)**	**Yield (Kg/m^2)**	**MPY (kg/m^2)**	**Crop water productivity (kg/ m^3)**	
					WP_{R+SI} (Kg/m^3)	**WP_{R+SIc} (Kg/m^3)**
Cabbage	662.2	424.88	3.10	3.5	4.68	8.24
Green Pepper	676	437.26	1.40	1.5	2.07	3.43
Swiss chared	601	436.65	1.03	1	1.71	2.29
Lettuce	601	443.48	0.92	1.5	1.53	3.38
Carrot	601	435.70	1.12	1	1.86	2.30
Potato	662	479.55	0.67	4	1.01	8.34

Table 25**.** The results of water productivity analysis for vegetable crops (For HM pond**).**

Crop type	**R+SI (mm)**	**R+SIc (mm)**	**Yield (Kg/m^2)**	**MPY (kg/m^2)**	**Crop water productivity (kg/ m^3)**	
					WP_{R+SI} (Kg/m^3)	**WP_{R+Sic} (Kg/m^3)**
Cabbage	458	351.31	2.00	3.5	4.37	9.96
Tomato	439	391.58	1.20	1.5	2.73	3.83
Green Pepper	458.45	570.40	0.53	1.5	1.15	2.63
Swiss chared	439	371.15	0.96	1	2.19	2.69

Generally, the actual supplementary water productivity (kg/m^3) is low when compared to the potential water productivity (kg/m^3). The causes for low WP would be inefficient water application method, which was bucket irrigation, and poor irrigation scheduling, which was irrigating the entire area of the garden with three-days interval. So households were not getting sufficient benefit from the ponds when compared to the material and labor input for pond construction. Hence, the resulted poor water productivity has negative impact on dissemination and adoption of household ponds in the region.

The main reason suggested for low water productivity could be lack of irrigation scheduling based on the climate, soil and crop of specific sites. For instance, as presented in (Table 12), the maximum amount of available soil water in the root zone obtained from HM backyard (Kilte Awlaelo), which was about 300 mm with a soil texture of Silt loam. On the other hand the minimum TAW was obtained from LK backyard, which is about 48 mm with a soil texture of sand. The moisture characteristics curve in (fig 10) indicated, the moisture content were high at field capacity for sand textured soil and it drops to wilting point rapidly, where as the moisture content of the loam textured soil depleted gradually. For clay-textured soil the amount of water was relatively high at wilting point because more water is held by soil particles by hygroscopic force, which is not available for the plant. The frequency and amount of irrigation (irrigation scheduling) is highly dependant on the soil moisture characteristics curve of the soil. For instance sandy soils require frequent watering with minimum amount of water whereas loam soils regime more amount of water with long irrigation interval.

4.6 Gross production economic water use

The gross production economic water use is an index for indicating the performance of the irrigation system on the bases of economic return. In other words, it is the economic return obtained in the season over the total water applied in the system (rainfall plus supplementary irrigation). Based on the result (Table 31-36), the average gross production economic water use index was about 4 ETB/Cubic meter of water. The higher economic return among the studied households were obtained from HA pond which was 5.5 ETB per cubic meter of water where as the minimum economic return were obtained from HB pond, which was 1.93 ETB per cubic meter of water. When we consider the economic return obtained from each crop type, Cabbage had relatively higher return, which was 13.82 ETB per cubic meter of water; where as, the list economic return was obtained from tomato 0.11 ETB per cubic meter of water. The investigation reveals that inefficient water use and poor management of the garden caused economic water productivity.

Table 26. The results of economic water productivity analysis for vegetable crops; Rainfall plus actual Supplementary irrigation (R+SI) in mm(HA back yard).

Type of crop	**[6]R+SI in mm**	**ETB/m^2**	**[7]WP_{R+SI} (ETB/m^3)**
Green Pepper	522.20	2.75	5.27
Onion	521.60	1.90	3.64
Potato	505.40	3.85	7.62
Average			**5.51**

[6] R+SI =Rainfall plus actual Supplementary irrigation
[7] WP_{R+SI} = economic water productivity of rainfall plus supplementary irrigation

Table 27. The results of economic water productivity analysis for vegetable crops; Rainfall plus actual Supplementary irrigation (R+SI) in mm(LK back yard).

Type of crop	**R+SI in mm**	**ETB/m²**	**WP_{R+SI} (ETB/m³)**
Cabbage	476.12	2.27	4.77
Green Pepper	478.00	0.33	0.69
Onion	476.00	1.00	2.10
Sweet potato	479.00	1.67	3.49
Potato	470.00	0.13	0.28
White cumin	476.00	0.99	2.08
Black cumin	476.00	0.93	1.95
Average			**2.19**

Table 28. The results of economic water productivity analysis for vegetable crops; Rainfall plus actual Supplementary irrigation (R+SI) in mm (HM back yard).

Type of crop	**R+SI in mm**	**ETB/m²**	**WP_{R+SI} (ETB/m³)**
Cabbage	458	3.00	6.55
Tomato	439	1.36	3.10
Green Pepper	458.45	2.63	5.74
Swiss chared	439	1.44	3.28
Average			**4.67**

Table 29. The results of economic water productivity analysis for vegetable crops; Rainfall plus actual Supplementary irrigation (R+SI) in mm(SW back yard).

Type of crop	**R+SI in mm**	**ETB/m²**	**WP_{R+SI} (ETB/m³)**
Cabbage	491.6	4.19	8.52
Tomato	492	0.11	0.22
Swiss chared	474.5	1.20	2.53
Lettuce	474.5	2.46	5.18
Carrot	474.5	1.26	2.66
White cumin	491	2.00	4.07
Black cumin	491	2.00	4.07
Average			**4.67**

Table 30. The results of economic water productivity analysis for vegetable crops; Rainfall plus actual Supplementary irrigation (R+SI) in mm (AT back yard).

Type of crop	**R+SI in mm**	**ETB/m²**	**WP_{R+I} (ETB/m³)**
Cabbage	662.2	9.15	13.82
Green Pepper	676	5.09	7.53
Swiss chared	601	2.18	3.63
Lettuce	601	0.92	1.53
Carrot	601	3.53	5.87
Potato	662	0.90	1.36
Average			**3.86**

Table 31. The results of economic water productivity analysis for vegetable crops; Rainfall plus actual Supplementary irrigation (R+SI) in mm (HB back yard).

Type of crop	**R+SI in mm**	**ETB/m²**	**WP_{R+I} (ETB/m³)**
Tomato	406.00	0.94	2.32
Green Pepper	415.00	0.10	0.24
Cucumber	388.00	1.25	3.22
Average			**1.93**

The economic water productivity was higher when compared with similar results obtained in Hyba dam, Tigray by Mintesinot *et al* (2005). The average economic productivity of the pond was estimated to be 3.8 ETB/m^3 whereas the average economic water productivity for vegetable crops (onion) in Hayba dam was 2.25 ETB/m^3. Here, the relative high economic water productivity would be due to conjunctive use of rainfall and supplementary irrigation.

4.7 Problems encountered in the expansion of ponds and homegarden

According to the assessment conducted in 30 farmers, which had ponds, and the same number of households, which didn't have ponds, the respondents mentioned the following points as the main problems to halt the active adoption of water harvesting ponds. These are:-

- The actual locations of the ponds were not convenient for the farmer to utilize the water effectively. About 70% of the constructed ponds are located far from their home, which was difficult for them to utilize the water effectively and protect the irrigated area from damage of livestock. Based on field observations ponds located far from their home was not well utilized when compared to pond found in their backyard. About 90 % of the respondents preferred the location of ponds to be in their backyard (Table 18 presents the result of the analysis). The main reason indicated by the studied households were, ponds near their residence are easy for management.

Table 32**.** Preferred location of the pond construction by the respondents

Location of ponds	**Frequency**	**Percent**
At homestead	54	90
On farm land	6	10
Total	**60**	**100**

- The actual design of ponds (Trapezoidal) was not preferred by most households. Because, it has high surface evaporation and large area needed (169 m^2) for construction. According to the survey, 93.4 % of the respondents complained on the existing common pond design whereas, the rest of the respondents had a positive attitude for its labor intensive and simplicity of the design.
- Based on farmer's observation, about 70% of the respondents explained that evaporation from the pond surface as a main loss. The rest of respondents indicated seepage as a main loss especially for clay lined ponds (Table 19)

Table 33**.** The comparison of main water losses from the pond

Types of water loss	Frequency	Percent
Seepage	9	30
Evaporation	21	70
Total	**30**	**100**

During the interview, the studied households mentioned that the following constraints for inefficient water utilization and hampering the expansion of homegarden practices.

- Lack of enough tree seedlings provision based on their prior preference. Hence, targeted households were asked to indicate which species of tree is highly required by them. Most of the respondents were interested to grow Orange and Guava seedling with adequate quantity. The combination of seedlings required by households was assessed and indicated below.

Table 34. Tree species preference by the households

S/N	Tree species	Frequency	Percent
1	*Banana*	1	3.3
2	*Coffee,Guava , Orange*	1	3.3
3	*Eucaleptus Spp.*	1	3.3
4	*Grape,Guava,Avucado,Apaya,Mango,Citrus Medica*	3	10
5	*Guava*	3	10
6	*Guava,Avucado,Apaya,Mango,Citrus Medica*	3	10
7	*Guava,Orange,Papaya,Mango,Citrus Medica*	2	6.7
8	*Orange*	5	16.7
9	*Orange And Avocado*	1	3.3
10	*Orange And Guava*	1	3.3
11	*Orange And Guava*	2	6.7
12	*Orange, Citrus Medica, Banana*	1	3.3
13	*Orange, Guava, Papaya*	1	3.3
14	*Orange And Coffee*	1	3.3
15	*Orange and Guava*	3	10
16	*Rhamnus*	1	3.3
	TOTAL	**30**	**100**

- Lack of training and technical support on planting, managing trees, irrigation scheduling and water application methods.
- Most of the respondents were using labor intensive and time taking irrigation water withdrawal and application method.

Table 35**.** Method of water application used by households

Method	**Frequency**	**Percent**
Direct watering by bucket or watering can	28	93.4
Gravity drip irrigation	2	6.6
Total	**30**	**100**

- Most of the respondents stated that the cost of some fruit tree seedlings were expensive. For instance, Orange, Avocado and Mango (two birr per seedling). Table 22 presents the frequency of households respond to the cost of seedlings. Accordingly, farmers should be subsidized seedling price in order to expand homegarden practices.

Table 36**.** Farmers perception on the costs of fruit tree seedling

Description	**Frequency**	**Percent**
Expensive	17	56.6
Fair	13	43.4
Total	**30**	**100**

Generally, most of the respondents indicated that the current design of household pond has the following drawbacks: Due to its big surface area, it is highly exposed for evaporation loss. This is also proved by scientific estimation (Penman combination method in Table 23) about 12% of the stored water was lost directly by surface evaporation. However on clay-lined ponds the seepage loss was estimated to be about 17.5% of the stored water. Besides, the ponds occupied large area of land, up to 169 m^2, which is about 35-40% of their backyard. As a result, recently most farmers are looking for other design options.

Chapter V: Conclusion and recommendation

5.1 Limitations

Evaluating the water productivity of household ponds was the difficult part of this study, because few similar investigations were conducted for small-scale irrigation scheme (ponds). Accordingly, the methodology of this part is not directly adopted from similar works instead it is modified from water productivity studies conducted for dams as well as river diversions.

Furthermore, the research was not including the productivity of perennial tree components of the homegarden, because trees will take at least 2- 3 years to give economic importance.

5.2 Conclusion

The construction of household ponds in Tigray region has been implemented in large scale since the fiscal year 2003. Even though about 51% of the constructed ponds harvested water, the utilization is very limited. Accordingly, from the constructed 53,899 ponds with in 2003 and 2004 year, about 24,652 ponds harvested water and only about 44% had been utilized partially for the developing vegetable gardens. As indicated in the finding of this study, the households were reluctant to take on the technology. The main reasons included the fact that the locations of most pond constructed were not appropriate for developing homegarden. Furthermore, actually farmers were not interested to use ponds for supplementing the staple crops, located far from their home compounds.

Accordingly, the result of the study indicated that the construction of household ponds had a great contribution on the expansion of homegarden. Households' interest to grow vegetable and trees around their home was initiated. Besides, the survival and growth of trees had improved by 15 % and 22 % respectively and the diversity of trees planted has shown a significant increase. Furthermore, the water productivity result indicated that the unit crop production per unit supplementary irrigation applied was 75% lower than the maximum potential water productivity; and the average economic productivity of the pond was estimated to be 3.8 ETB per cubic meter of water. The study reveals that among the reasons for low water productivity were inefficient water application and withdrawal method, poor knowledge of irrigation scheduling, poor selection of crop type and cropping calendar.

The study specified that the actual design of household ponds is exposed for high evaporation loss (12% of the harvested water) and the pond occupies large area (40% of their backyard) for construction. This might be one of the reasons for the current design to be rejected by most farmers. So as to avoid this problem, additional design alternative are essential instead of the trapezoidal shaped ponds, even though the costs of lining is relatively expansive for options such as cylindrical pond.

Generally, the study results indicated that the water harvesting household ponds in the region had poor in site selection, design, water management, crop selection and cropping pattern. However, limited interested households have got better results with homegarden, which they were developed after the implementation of household ponds.

5.3 Recommendation

Based on the results obtained from the study, the following are recommended:

- The location of household pond construction preferred to be on the backyard of the farmers so as to ease protection and management of fruit trees and vegetable crops; effective utilization of the water in the ponds and to use the household labor effectively. However, pond construction on farmland is possible with controlled and zero grazing interventions.

- The evaporation loss from the existing pond design (Trapezoidal) is very high so other design alternative should be considered such as Cylindrical pond that reduced 37% of the evaporation surface when compared to trapezoidal ponds, more over; cylindrical ponds occupies about 37% less land than trapezoidal ponds.

- The yield of irrigated horticulture crops is very low; strengthened extension services along with the provision of inputs such as improved seeds of vegetables and spices and provision of fruit tree seedlings based on the preference of households is required. These should include Orange, Guava and Mango seedlings, which will play a significant role in rising the benefits and contributions to the household food security.

- The water application method should be more efficient so as to improve the water productivity. Here the application of family drip technology is recommended.

- Different water harvesting options should be available to offer to the communities to take account of different agro ecological, geological, social and economic situations.

- Promotion of household ponds should consider greater community involvement in planning and implementation than the current practices.

A strengthened irrigation extension service to the farmers is essential if potential benefits of rainwater harvesting ponds are to be released. So detail and further study is required in the following areas

1. The development and transfer of alternative irrigation technologies with high water productivity and suitable for irrigation.

2. Developing new guideline for irrigation scheduling under water scarce conditions.

3. Detail assessment of household pond economical and environmental impact and their contribution to livelihood.

4. Providing socio economic incentives for improved water management at the farm level and development of appropriate policy.

5. The effect of ponds on health (malaria) and biological pollution issues. Besides, large-scale assessment of farmers preference on pond location, design and implementation approach

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Appendix

APPENDIX A . Tree inventory data with and without the application of supplementary irrigation

Table A.1. Tree inventory data with and without the application of supplementary irrigation (Inventory conducted in Oct.2003)

Tree species name	***With supp. Irr.***	***Without supp. Irr.***	***Total***
Citrus sinesis	117	42	159
Citrus medica	8	6	14
Citrus reticulate	15		15
Mangifera indica	49		49
Psidium guajava	428	328	756
Persea Americana	3	15	18
Rhamnus prinoides	106	85	191
Catha edulis		8	8
Papaya	190	92	282
Banana	31	9	40
Sesbania sesban	692	167	859
Leucaena leucocephala	100		100
Eucalyptus globules		85	85
Eucalyptus camaldulensis	3519	1545	5064
Coffee tree	24	133	157

APPENDIX B. Meteorological data

Table B.1 Monthly mean sun shine
Region Tigray
Station Mekelle Airport

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov
1991	X	X	X	X	X	X	5.4	5.4	7.2	9.5	9.8
1992	8.2	9.1	9.0	9.5	9.8	8.1	5.0	3.8	6.9	7.9	8.3
1993	9.7	8.4	9.5	8.4	9.3	7.1	5.4	5.9	8.5	8.5	10.4
1994	10.3	9.9	9.0	9.5	10.1	6.4	4.4	5.1	10.5	10.5	9.8
1995	10.3	8.9	9.3	9.1	9.3	9.2	5.4	5.1	9.8	9.8	10.0
1996	9.0	9.6	8.2	9.2	8.4	5.9	6.1	5.7	9.8	9.8	9.0
1997	9.5	9.9	8.6	9.1	9.6	8.0	6.0	6.5	8.1	8.1	8.9
1998	8.4	8.7	9.1	9.4	9.4	7.3	4.9	4.1	7.1	9.2	10.2
1999	9.3	10.3	9.7	10.4	9.9	6.9	3.9	5.2	8.1	8.9	10.4
2000	10.1	10.0	10.0	7.8	9.6	7.7	X	X	6.9	9.0	9.0
2001	9.6	9.7	6.4	X	X	X	X	X	8.6	9.3	10.3
2002	9.3	10.1	8.9	10.4	10.6	11.9	7.4	7.4	8.5	10.3	10.0
2003	9.9	9.4	9.6	9.3	10.5	6.8	4.4	4.4	8.3	10.5	10.3
2004	9.8	10.0	10.1	8.8	10.9	6.7	5.8	5.8	7.8	10.1	10.2
Aver	9.5	9.5	9.0	9.2	9.8	7.7	5.3	5.4	8.3	9.4	9.8

Table B.2. Monthly mean wind speed (M/S)
Region: Tigray
Station: Mekele Airport

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1995	X	X	X	X	X	X	X	X	1.93	3.35	3.36	3.65
1996	3.58	4.00	3.69	4.09	2.96	1.92	2.04	1.64	1.99	3.34	3.57	3.75
1997	3.27	4.89	3.88	3.80	3.61	2.25	1.68	1.39	2.32	3.65	3.78	3.78
1998	3.52	3.20	4.36	4.78	3.42	2.43	2.33	1.74	1.58	2.67	3.30	3.52
1999	3.46	4.21	3.71	4.23	2.90	2.13	1.86	1.60	1.53	2.66	3.38	3.57
2000	3.74	4.43	4.72	3.44	2.99	2.17	2.09	1.89	1.71	2.80	3.16	3.27
2001	3.03	3.34	3.81	3.61	3.07	2.01	1.99	1.61	1.49	2.96	3.88	4.06
2002	3.49	3.61	3.18	3.43	2.66	2.01	1.54	1.52	1.96	3.02	3.34	3.09
2003	3.03	3.34	3.81	3.61	3.07	2.01	1.99	1.61	1.49	2.96	3.88	4.06
Aver	3.39	3.88	3.90	3.87	3.09	2.12	1.94	1.63	1.78	3.05	3.52	3.64

Table B.3. Monthly mean Rel. Hum. At 600 L.S.T

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1993	89.0	84.0	78.0	91.0	89.0	90.0	94.0	94.0	86.0	84.0	83.0	79.0
1994	75.0	82.0	85.0	74.0	64.0	78.0	94.0	97.0	90.0	77.0	85.0	83.0
1995	80.0	85.0	90.0	89.0	84.0	76.0	95.0	98.0	86.0	73.0	77.0	88.0
1996	94.0	81.0	86.0	87.0	79.0	84.0	91.0	96.0	83.0	90.0	72.0	70.0
1997	78.0	73.0	75.0	76.0	69.0	81.0	96.0	94.0	83.0	88.0	90.0	86.0
1998	89.0	76.0	81.0	73.0	61.0	64.0	94.0	98.0	89.0	77.0	68.0	71.0
1999	78.0	55.0	74.0	62.0	53.0	59.0	93.0	96.0	87.0	84.0	75.0	82.0
2000	72.0	55.0	67.0	69.0	61.0	60.0	87.0	94.0	83.0	88.0	81.0	79.0
2001	84.0	75.0	79.0	69.0	67.0	75.0	93.0	94.0	83.0	83.0	X	X
2002	91.0	68.0	75.0	68.0	43.0	69.0	88.0	94.0	81.0	77.0	74.0	90.0
2003	81.0	76.0	80.0	73.0	59.0	65.0	93.0	97.0	x	73.0	X	X
Average	82.8	73.6	79.1	75.5	66.3	72.8	92.5	95.6	85.1	81.3	78.3	80.9

Table B.4 Monthly mean Rel. Hum. At 1200 L.S.T

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1993	48.0	42.0	38.0	68.0	65.0	66.0	72.0	69.0	53.0	50.0	54.0	44.0
1994	45.0	47.0	46.0	36.0	28.0	39.0	68.0	74.0	55.0	34.0	48.0	42.0
1995	37.0	44.0	40.0	50.0	40.0	36.0	73.0	77.0	47.0	37.0	35.0	43.0
1996	47.0	37.0	42.0	34.0	43.0	49.0	59.0	70.0	44.0	33.0	39.0	34.0
1997	36.0	31.0	34.0	32.0	31.0	45.0	68.0	62.0	33.0	42.0	47.0	35.0
1998	44.0	33.0	33.0	29.0	28.0	28.0	69.0	76.0	48.0	36.0	28.0	29.0
1999	36.0	20.0	28.0	24.0	20.0	26.0	72.0	75.0	47.0	45.0	39.0	42.0
2000	30.0	21.0	34.0	29.0	26.0	30.0	63.0	73.0	44.0	42.0	38.0	35.0
2001	38.0	29.0	37.0	29.0	24.0	38.0	70.0	77.0	44.0	38.0	X	X
2002	49.0	31.0	34.0	27.0	20.0	33.0	56.0	68.0	41.0	40.0	34.0	43.0
2003	31.0	32.0	35.0	34.0	24.0	34.0	64.0	74.0	46.0	36.0	34.0	34.0
Average	40.1	33.4	36.5	35.6	31.7	38.5	66.7	72.3	45.6	39.4	39.6	38.1

Table B.5. Monthly mean Rel. Hum. At 1800 L.S.T

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1993	71.0	63.0	52.0	75.0	71.0	67.0	78.0	72.0	55.0	56.0	61.0	55.0
1994	55.0	61.0	66.0	43.0	36.0	53.0	73.0	82.0	64.0	44.0	56.0	55.0
1995	50.0	55.0	54.0	59.0	45.0	40.0	78.0	79.0	50.0	38.0	43.0	64.0
1996	65.0	53.0	57.0	65.0	46.0	53.0	66.0	76.0	48.0	37.0	52.0	47.0
1997	58.0	48.0	55.0	51.0	35.0	47.0	74.0	64.0	33.0	53.0	62.0	54.0
1998	67.0	50.0	53.0	43.0	33.0	30.0	76.0	86.0	56.0	48.0	37.0	42.0
1999	50.0	32.0	49.0	31.0	22.0	26.0	77.0	80.0	49.0	57.0	45.0	55.0
2000	48.0	38.0	46.0	37.0	30.0	33.0	66.0	77.0	48.0	56.0	55.0	55.0
2001	58.0	48.0	56.0	35.0	35.0	52.0	77.0	81.0	53.0	49.0	X	X
2002	72.0	47.0	52.0	37.0	27.0	42.0	55.0	69.0	47.0	40.0	41.0	67.0
2003	54.0	53.0	55.0	47.0	26.0	39.0	70.0	80.0	56.0	39.0	44.0	51.0
Average	58.9	49.8	54.1	47.5	36.9	43.8	71.8	76.9	50.8	47.0	49.6	54.5
MEAN R H	**60.61**	**52.27**	**56.55**	**52.91**	**44.97**	**51.73**	**77.03**	**81.61**	**60.52**	**55.88**	**55.84**	**57.83**

Table B.6. Monthly Maximum Temprature (^oC)
Station Mekele Airport

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1959	X	X	X	X	X	27.1	21.9	21.5	22.7	19.5	22.8	22.7
1960	21.7	24.8	25.1	26.3	26.6	27.9	22.5	22.3	23.2	23.8	23.5	22.6
1961	23.9	23.4	24.9	25.9	27.6	27.1	20.8	21.2	24.3	23.6	21.4	21.7
1962	22.3	24.3	24.4	26.2	27.2	28.2	25.2	22.5	24.2	22.9	21.7	22.4
1963	21.1	23.6	25	25	26.5	27.5	23.3	23.2	25.6	25.5	24.2	23.3
1964	24.7	26.8	27.8	26.7	28.9	28.8	23	23.1	25.2	23.5	23.5	22.6
1965	24.4	24.6	25.7	26.5	28.7	29	25.6	23	25.9	25.1	23.6	24.3
1966	24.9	25.7	26.9	27	28.6	29.2	25.4	24	25.2	25.2	23.4	24
1967	24.4	26.4	26.5	26.7	27.6	27.9	22.7	22.3	25.4	23.9	23.2	23.6
1968	24.1	24.5	26.1	26.2	27.3	27.3	23.2	24	26.6	25.2	23.9	24.7
1969	24.1	24.8	25.1	27	27.8	29.9	24.5	23.7	25.3	25.9	24.7	24.3
1970	25.5	26.9	26.9	27.3	29.4	29.2	24.8	22.6	25	24.4	23.3	22.8
1971	23.1	25.5	25.5	27.2	26.8	27.4	24.4	24.1	23.9	24.9	23.6	23.4
1972	25.3	25.5	26.9	26.9	27.8	27.4	24.5	24.9	26.6	25.2	24.9	24.7
1973	26.5	27	28.7	28.3	28.4	29.4	24.6	23.9	25.4	22.3	21.7	20.3
1974	22	22.4	21.8	24.7	24.8	25.9	21.7	21.8	24.9	22.6	20.5	21.2
1975	21.5	22.4	24	24.4	26.2	24.4	21.9	20.5	23	22.2	20.2	20.1
1976	21.5	23	X	23.7	24.7	27.3	22.6	21.4	24.3	22.9	21.1	21.1
1977	22	21.9	23.1	25.8	25.2	25.3	21.8	21.6	24.1	X	21.3	20.8
1978	21.4	23.4	24.1	24.8	26.9	26.2	20.5	21.7	24.7	22.4	20.6	20.5
1979	20.3	22.9	24.3	24.7	24.6	25.8	23.3	22.7	24.8	23.7	22.7	23.1
1980	23.3	23.8	25.6	25.7	26.8	26.7	x	22.4	24.2	23.6	22.5	22.3
1981	23.1	24.2	24.1	25.3	26.8	27.7	22.8	22.2	23.6	23.5	22.5	22
1982	23.2	24.2	24.4	25	25.8	27.5	23.8	22.2	24.1	22.8	22.7	22.8
1983	22.9	25.1	26.8	26.7	26.5	27.5	25.8	22.3	24.9	24.1	23.7	23
1984	23.1	24.5	26.2	27.2	26.7	26.8	23.8	23.6	24.3	24.1	23.1	21.7
1985	23.8	X	24.5	24	25.5	27.2	23.6	22.5	24.1	23.5	22.8	22.1
1986	X	X	X	X	X	X	x	X	x	X	X	X
1987	22.7	24.6	24.4	24.6	25.7	X	x	23.3	x	X	23.7	22.4
1988	22.8	23.1	24.5	25.9	26.1	27	22.3	21.2	23.3	24.1	22.6	21.2
1989	21.7	X	X	X	X	X	x	X	x	X	X	X
1990	X	X	X	X	X	25.8	23	21.7	23.3	23.1	21.7	21.6
1991	X	X	X	X	X	25.8	22.9	21.8	24	23.1	21.6	21.6
1992	21.7	23.3	24.4	25.4	26	27.6	23.2	20.4	22.8	22.5	20.2	20.8
1993	20.7	21.8	23.6	22.2	24.0	25.3	22.3	22.9	24.4	23.1	21.8	21.5
1994	21.9	22.8	24.2	24.9	26.1	25.7	21.3	21.0	22.5	23.1	21.9	21.2
1995	22.1	24.0	24.6	24.6	25.8	28.2	22.9	22.1	23.9	23.4	22.8	22.8
1996	23.1	24.9	24.9	25.6	25.0	24.4	23.2	22.5	25.0	23.7	22.1	21.6
1998	23.7	25.2	26.1	27.2	27.0	27.8	22.4	21.3	23.9	23.3	22.2	21.8
1997	23.3	23.5	25.7	25.5	26.6	26.6	22.8	23.1	25.6	23.3	22.6	23.1
1999	22.3	24.9	25.0	26.3	27.9	27.9	21.7	21.4	23.5	X	X	X
2000	X	23.9	24.9	25.6	27.5	27.9	23.6	22.3	24.0	23.6	22.7	22.5
2001	23.1	24.5	24.5	26.4	28.1	25.5	22.6	31.9	24.6	24.5	22.8	22.6
2002	22.3	24.6	25.8	26.5	28.7	27.3	25.5	23.3	24.9	24.8	23.5	23.4
2003	24.5	25.6	25.7	26.6	27.3	26.9	23.4	22.3	24.3	23.6	22.8	22.0
2004	25.0	24.0	25.0	25.9	28.2	26.5	24.8	22.9	25.1	23.5	23.0	22.9
Average	23.05	24.31	25.19	25.81	26.82	27.16	23.24	22.65	24.43	23.63	22.58	22.35

Table B.7 Monthly Minimum Temperature (^oC)

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1959	X	X	x	X	X	12.3	12.4	11.5	9.2	9.4	8.5	8.6
1960	8.6	9.8	10.9	12.4	12.7	12.9	11.9	11.9	10.5	9.5	8.2	8.9
1961	8.9	9.5	10.8	12.8	13.1	11.9	11.6	11.6	10.1	9.8	9.9	9.3
1962	8.1	8.6	11.6	12	12.9	12.8	11.7	12	11.2	8.9	9.4	8.8
1963	8.6	9.8	11.3	12	12.4	12.5	11.8	12.1	11.2	11.5	12.3	9.4
1964	11	10.9	12.1	13.4	14.2	14	12.3	12.4	11.6	10.7	8.4	8.9
1965	8.5	10.4	10.6	13.8	14.8	13.8	13	12.5	11	10.7	10.9	9.3
1966	9.4	10.8	12.2	13.9	14.2	14.1	13.2	12.5	12.1	11.5	10.2	7.4
1967	7.2	9.3	12	13.3	13.6	13.9	12.9	11.8	11.5	11.1	10.7	8.3
1968	8.3	8.9	11.5	12.6	14.9	13.4	12.5	12	12.1	12.2	10.1	8.3
1969	10.3	10.4	11.9	13.9	14.2	14.3	13	12.6	11.8	11.1	9.7	7.3
1970	9.2	10.3	11.9	13.9	14.6	14.3	13	13	10.9	12.4	8.4	7.3
1971	8.5	9.3	11.4	13.7	13.4	13.3	12.8	12.9	12	12	9.7	8
1972	9.4	9.9	12.1	14	13.8	14.2	12.6	12.3	12	12.4	11	11
1973	9.6	9.9	11.8	13	14	14	12.7	13.1	12.2	11.1	10.1	7.8
1974	8.9	9.6	10.7	13.1	13.3	13.5	11.5	11.8	11.9	11.1	8.5	8.8
1975	9.3	10.9	12.2	12.8	14	12.6	12.3	12	11.7	10.7	9.5	9
1976	9.3	10.7	x	12.4	13.2	13.1	12.2	11.8	11.5	11.3	10.2	8.2
1977	8.4	8.9	9.7	9.5	9.7	10.6	9.6	9.2	8.6	x	8.8	X
1978	9.6	11.4	12.3	14.2	14.8	14.4	12.6	12.1	11.8	11.7	10.3	5.3
1979	5.1	5.8	7.8	8.9	10	10.2	8.9	7.7	11.8	10.8	9	9.1
1980	8.9	10.7	11.7	12.5	13.5	13	X	12.3	11.2	10.2	9.4	8
1981	8.4	9.4	11.7	12.3	13.2	13.1	12.6	12.5	10.6	9.2	8.1	6.4
1982	8.7	8.8	10.2	10.8	11.5	12.3	11.3	11	9.9	9.1	9.2	7.9
1983	6.9	7.8	10	11.4	12.2	12.3	12	11.7	10.1	9.3	8.3	7.1
1984	6.5	7.1	10.3	12.3	12.1	12.5	11.9	11.4	10.8	9.4	9.9	8.3
1985	8.6	X	9.4	10.2	11.7	11.9	11.1	11.6	10	10.6	9.6	8.2
1986	X	X	x	X	X	X	X	X	X	x	x	X
1987	1.6	3.7	4.2	9.2	11	11.3	11.4	11	11.2	11	8.6	8.4
1988	9.4	10.2	11	12.4	12.5	12.1	9.3	11.1	11.6	9.1	4.5	2.1
1989	2.9	X	x	X	X	X	X	X	X	x	x	X
1990	X	X	x	X	X	X	X	X	X	x	x	X
1991	X	X	x	X	X	16.5	13.7	12.8	12	11	9.6	9.7
1992	9.9	9.7	11.9	13.2	13.8	13.2	12.4	12.8	11.2	10.9	10.4	10.8
1993	9.6	9.6	11.7	12.5	13.1	13.0	12.6	12.6	11.7	12.1	10.8	9.4
1994	9.5	10.6	11.7	13.8	14.4	12.9	13.0	12.9	10.7	10.6	10.6	9.2
1995	9.3	9.8	11.9	14.0	14.5	13.7	12.7	13.3	11.2	11.1	10.1	10.4
1996	9.6	10.6	12.5	13.3	13.6	12.6	13.1	13.2	11.7	11.2	10.2	9.4
1997	9.3	10.1	12.4	13.0	13.5	14.4	13.2	12.7	12.4	12.4	12.2	10.3
1998	10.8	10.2	12.8	14.9	14.5	14.4	14.0	13.9	12.6	11.5	8.9	8.3
1999	9.4	10.6	11.1	13.5	13.9	13.7	12.8	12.9	12.1	11.5	9.5	9.5
2000	9.5	10.4	11.7	12.9	13.7	13.5	13.2	13.6	11.8	11.3	10.6	10.1
2001	8.1	10.1	12.2	13.8	14.5	13.3	13.3	13.4	12.1	11.9	9.6	10.3
2002	10.5	10.7	12.4	12.2	14.1	13.8	13.7	12.7	12.2	11.6	11.0	10.5
2003	8.7	11.7	12.3	13.7	15.2	13.5	13.8	12.7	11.7	10.7	10.6	9.3
2004	10.1	9.7	11.6	13.4	13.2	13.2	13.0	13.0	11.6	10.0	11.0	9.9
Average	8.63	9.67	11.24	12.70	13.35	13.17	12.35	12.18	11.33	10.85	9.69	8.63

Table B.8.Rainfall amount for 2004 year in Adigudum Rain Gauge station

June		July		August		September	
Date	rain fall in mm	Date	rain fall in mm	Date	Rain fall in mm	Date	rain fall in mm
6/1/2004		7/1/2004	0	8/1/2004	2.3	9/1/2004	0
6/2/2004		7/2/2004	0	8/2/2004	1	9/2/2004	8.12
6/3/2004		7/3/2004	2.8	8/3/2004	4.9	9/3/2004	
6/4/2004		7/4/2004	0.3	8/4/2004	53.8	9/4/2004	
6/5/2004		7/5/2004	0	8/5/2004	42.6	9/5/2004	
6/6/2004		7/6/2004	0	8/6/2004	10.7	9/6/2004	
6/7/2004		7/7/2004	0	8/7/2004	7.2	9/7/2004	
6/8/2004	0	7/8/2004	0	8/8/2004	0	9/8/2004	
6/9/2004	0	7/9/2004	0	8/9/2004	0	9/9/2004	
6/10/2004	0	7/10/2004	21.6	8/10/2004	0.9	9/10/2004	
6/11/2004	0	7/11/2004	0	8/11/2004	2.7	9/11/2004	
6/12/2004	0	7/12/2004	13.9	8/12/2004	14.3	9/12/2004	
6/13/2004	0	7/13/2004	7.4	8/13/2004	1.3	9/13/2004	
6/14/2004	0.4	7/14/2004	1.6	8/14/2004	0.8	9/14/2004	
6/15/2004	6.2	7/15/2004	0	8/15/2004	0	9/15/2004	
6/16/2004	0.4	7/16/2004	2	8/16/2004	5.5	9/16/2004	
6/17/2004	1.9	7/17/2004	0	8/17/2004	13.86	9/17/2004	
6/18/2004	2	7/18/2004	0	8/18/2004	3.7	9/18/2004	
6/19/2004	0	7/19/2004	0.9	8/19/2004	0	9/19/2004	
6/20/2004	0	7/20/2004	1	8/20/2004	6.1	9/20/2004	
6/21/2004	3.4	7/21/2004	0	8/21/2004	0	9/21/2004	
6/22/2004	0	7/22/2004	1.3	8/22/2004	0	9/22/2004	
6/23/2004	4.6	7/23/2004	1.3	8/23/2004	1	9/23/2004	
6/24/2004	10.2	7/24/2004	1.5	8/24/2004	0	9/24/2004	
6/25/2004	0.6	7/25/2004	2.1	8/25/2004	11.97	9/25/2004	
6/26/2004	0	7/26/2004	1.1	8/26/2004	0	9/26/2004	
6/27/2004	0	7/27/2004	8.8	8/27/2004	0	9/27/2004	
6/28/2004	0	7/28/2004	8.8	8/28/2004	7.5	9/28/2004	
6/29/2004	0.03	7/29/2004	7.8	8/29/2004	0	9/29/2004	
6/30/2004	0	7/30/2004	12.2	8/30/2004	0	9/30/2004	
		7/31/2004	6.4	8/31/2004	0		
Total	**29.73**		**102.8**		**192.13**		**8.12**

Table B.9.Rainfall amount for 2004 year in Abrha Atsbha raingauge station

June		July		August		Sept	
Date	**Amount in mm**	**Date**	**Amount in mm**	**Date**	**Amount in mm**	**Date**	**Amount in mm**
6/1/2004	0.0	7/1/2004	0.0	8/1/2004	0.0	9/1/2004	0.0
6/2/2004	0.0	7/2/2004	0.0	8/2/2004	17.0	9/2/2004	0.0
6/3/2004	0.0	7/3/2004	0.0	8/3/2004	35.0	9/3/2004	0.0
6/4/2004	0.0	7/4/2004	0.0	8/4/2004	19.0	9/4/2004	0.0
6/5/2004	0.0	7/5/2004	0.0	8/5/2004	0.0	9/5/2004	0.0
6/6/2004	0.0	7/6/2004	0.0	8/6/2004	0.0	9/6/2004	0.0
6/7/2004	0.0	7/7/2004	0.0	8/7/2004	0.0	9/7/2004	0.0
6/8/2004	0.0	7/8/2004	0.0	8/8/2004	0.0	9/8/2004	0.0
6/9/2004	0.0	7/9/2004	0.0	8/9/2004	0.0	9/9/2004	0.0
6/10/2004	0.0	7/10/2004	0.0	8/10/2004	0.0	9/10/2004	0.0
6/11/2004	0.0	7/11/2004	0.0	8/11/2004	0.0	9/11/2004	0.0
6/12/2004	0.0	7/12/2004	0.0	8/12/2004	0.0	9/12/2004	0.0
6/13/2004	0.0	7/13/2004	0.0	8/13/2004	0.0	9/13/2004	0.0
6/14/2004	0.0	7/14/2004	23.0	8/14/2004	15.0	9/14/2004	0.0
6/15/2004	0.0	7/15/2004	6.0	8/15/2004	10.0	9/15/2004	0.0
6/16/2004	5.0	7/16/2004	13.0	8/16/2004	23.0	9/16/2004	0.0
6/17/2004	0.0	7/17/2004	0.0	8/17/2004	7.0	9/17/2004	0.0
6/18/2004	0.0	7/18/2004	0.0	8/18/2004	0.0	9/18/2004	0.0
6/19/2004	0.0	7/19/2004	0.0	8/19/2004	0.0	9/19/2004	0.0
6/20/2004	0.0	7/20/2004	14.0	8/20/2004	15.0	9/20/2004	0.0
6/21/2004	0.0	7/21/2004	19.0	8/21/2004	7.0	9/21/2004	0.0
6/22/2004	0.0	7/22/2004	21.0	8/22/2004	0.0	9/22/2004	0.0
6/23/2004	0.0	7/23/2004	0.0	8/23/2004	0.0	9/23/2004	0.0
6/24/2004	0.0	7/24/2004	17.0	8/24/2004	0.0	9/24/2004	0.0
6/25/2004	0.0	7/25/2004	0.0	8/25/2004	0.0	9/25/2004	0.0
6/26/2004	0.0	7/26/2004	40.0	8/26/2004	0.0	9/26/2004	0.0
6/27/2004	20.0	7/27/2004	9.0	8/27/2004	0.0	9/27/2004	0.0
6/28/2004	0.0	7/28/2004	6.0	8/28/2004	0.0	9/28/2004	0.0
6/29/2004	0.0	7/29/2004	0.0	8/29/2004	5.0	9/29/2004	0.0
6/30/2004	0.0	7/30/2004	0.0	8/30/2004	0.0	9/30/2004	0.0
		7/31/2004	0.0	8/31/2004	0.0		
Total	**25.0**		**168.0**		**153.0**		**0**

Table B.10.Rainfall amount for 2004 year in Agula rain gauge station

June		July		August		Sept	
Date	Amount in mm	Date	Amount in mm	Date	Amount in mm	Date	Amount in mm
6/1/2004	0.0	7/1/2004	0.0	8/1/2004	0.0	9/1/2004	0.0
6/2/2004	0.0	7/2/2004	0.0	8/2/2004	15.0	9/2/2004	0.0
6/3/2004	0.0	7/3/2004	0.0	8/3/2004	35.0	9/3/2004	0.0
6/4/2004	0.0	7/4/2004	0.0	8/4/2004	15.0	9/4/2004	0.0
6/5/2004	0.0	7/5/2004	0.0	8/5/2004	4.0	9/5/2004	0.0
6/6/2004	0.0	7/6/2004	3.0	8/6/2004	8.0	9/6/2004	0.0
6/7/2004	0.0	7/7/2004	0.0	8/7/2004	0.0	9/7/2004	0.0
6/8/2004	0.0	7/8/2004	0.0	8/8/2004	48.0	9/8/2004	0.0
6/9/2004	0.0	7/9/2004	0.0	8/9/2004	15.0	9/9/2004	0.0
6/10/2004	0.0	7/10/2004	0.0	8/10/2004	38.0	9/10/2004	0.0
6/11/2004	0.0	7/11/2004	0.0	8/11/2004	15.0	9/11/2004	0.0
6/12/2004	0.0	7/12/2004	0.0	8/12/2004	0.0	9/12/2004	0.0
6/13/2004	0.0	7/13/2004	0.0	8/13/2004	0.0	9/13/2004	0.0
6/14/2004	0.0	7/14/2004	6.0	8/14/2004	12.0	9/14/2004	0.0
6/15/2004	0.0	7/15/2004	16.0	8/15/2004	0.0	9/15/2004	0.0
6/16/2004	0.0	7/16/2004	0.0	8/16/2004	25.0	9/16/2004	0.0
6/17/2004	11.0	7/17/2004	0.0	8/17/2004	12.0	9/17/2004	0.0
6/18/2004	0.0	7/18/2004	0.0	8/18/2004	0.0	9/18/2004	0.0
6/19/2004	0.0	7/19/2004	0.0	8/19/2004	0.0	9/19/2004	0.0
6/20/2004	0.0	7/20/2004	12.0	8/20/2004	0.0	9/20/2004	0.0
6/21/2004	0.0	7/21/2004	0.0	8/21/2004	15.0	9/21/2004	0.0
6/22/2004	0.0	7/22/2004	0.0	8/22/2004	0.0	9/22/2004	0.0
6/23/2004	10.0	7/23/2004	0.0	8/23/2004	0.0	9/23/2004	0.0
6/24/2004	0.0	7/24/2004	0.0	8/24/2004	0.0	9/24/2004	0.0
6/25/2004	0.0	7/25/2004	14.0	8/25/2004	0.0	9/25/2004	0.0
6/26/2004	14.0	7/26/2004	30.0	8/26/2004	0.0	9/26/2004	0.0
6/27/2004	5.0	7/27/2004	0.0	8/27/2004	0.0	9/27/2004	0.0
6/28/2004	0.0	7/28/2004	9.0	8/28/2004	0.0	9/28/2004	0.0
6/29/2004	0.0	7/29/2004	0.0	8/29/2004	0.0	9/29/2004	0.0
6/30/2004	0.0	7/30/2004	0.0	8/30/2004	0.0	9/30/2004	0.0
		7/31/2004	11.0	8/31/2004	0.0		
Total	**40.0**		**101.0**		**257.0**		**0**

Table B. 11. Summerized metrological data of Hintalo waierate woreda (1959-2005)

Data type	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Rain fall(mm)						29.73	102.8	192.1	8.12			
Sunshine hour(Hr/Day)	9.49	9.54	9.03	9.24	9.78	7.67	5.34	5.37	8.29	9.39	9.76	9.79
Wind speed(M/S)	3.39	3.88	3.90	3.87	3.09	2.12	1.94	1.63	1.78	3.05	3.52	3.64
Relative humidity (%)	61	52	57	53	45	52	77	82	61	56	56	58
Adjusted Mean max temp. (^oC)	23.12	24.38	25.26	25.89	26.89	27.23	23.31	22.72	24.50	23.71	22.66	22.42
Adjusted Mean min. temp. (^oC)	8.70	9.74	11.31	12.78	13.43	13.24	12.42	12.26	11.40	10.92	9.76	8.70
Solar rad. ($MJ/M^2/d$)	20.30	21.90	22.70	23.70	24.40	24.00	17.40	17.70	21.80	22.20	21.00	20.10
Eto(PET) (mm/d)	4.41	5.42	5.61	6.02	6.16	5.94	3.59	3.42	4.45	4.91	4.67	4.46
Eto(PET) (mm/month)	136.71	151.76	173.91	180.6	190.96	178.2	111.29	106	133.5	152.21	140.1	138.26

Table B. 12 Summarized metrological data of Haykemeshale area(1959-2005)

Data type	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Rain fall(mm)						40	101	257	0			398
Sunshine hour(Hr/Day)	9.49	9.54	9.03	9.24	9.78	7.67	5.34	5.37	8.29	9.39	9.76	9.79
Wind speed(M/S)	3.39	3.88	3.90	3.87	3.09	2.12	1.94	1.63	1.78	3.05	3.52	3.64
Relative humidity(%)	61	52	57	53	45	52	77	82	61	56	56	58
Adjusted Mean max temp. (^oC)	23.46	24.72	25.60	26.22	27.23	27.57	23.64	23.06	24.84	24.04	22.99	22.76
Adjusted Mean min. temp. (^oC)	9.04	10.07	11.65	13.11	13.76	13.58	12.76	12.59	11.74	11.26	10.09	9.04
Solar rad. ($MJ/M^2/d$)	20.30	21.90	22.70	23.70	24.40	24.00	17.40	17.70	21.80	22.20	21.00	20.10
Eto(PET) (mm/d)	4.46	5.42	5.61	6.02	6.16	5.94	3.59	3.42	4.45	4.91	4.67	4.46
Eto(PET) (mm/month)	138.26	151.76	173.91	180.60	190.96	178.20	111.29	106.02	133.50	152.21	140.10	138.26

Table 37.Summarized metrological data of kilte awulaelo woreda (1959-2005)

Data type	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Rain fall(mm)						25	168	153	0			346
Sunshine hour(Hr/Day)	9.49	9.54	9.03	9.24	9.78	7.67	5.34	5.37	8.29	9.39	9.76	9.79
Wind speed(M/S)	3.39	3.88	3.90	3.87	3.09	2.12	1.94	1.63	1.78	3.05	3.52	3.64
Relative humidity (%)	61	52	57	53	45	52	77	82	61	56	56	58
Adjusted Mean max temp. (^oC)	24.14	25.40	26.28	26.91	27.91	28.25	24.33	23.74	25.52	24.73	23.68	23.44
Adjusted Mean min. temp. (^oC)	9.72	10.76	12.33	13.80	14.45	14.26	13.44	13.28	12.42	11.94	10.78	9.72
Solar rad. ($MJ/M^2/d$)	20.30	21.90	22.70	23.70	24.40	24.00	17.40	17.70	21.80	22.20	21.00	20.10
Eto(PET) (mm/d)	4.54	5.53	5.72	6.14	6.26	6.05	3.65	3.47	4.52	5.00	4.77	4.54
Eto(PET) (mm/month)	140.74	154.84	177.32	184.2	194.06	181.5	113.15	107.6	135.6	155	143.1	140.74

APPENDIX C . Estimation of evaporation loss

Table C.1. Estimation of monthly evaporation loss by Penman combination method (Amare Taere pond)

Month	Jan	Feb	Mar	April	May	June	July	Aug	sep	Oct	Nov	Dec	Total
No of days in the month	31	28	31	30	31	30	31	31	30	31	30	31	
Pond surface area (A in $M^{2)}$									144.00	81.00	63.00	30.00	
T_{min}	9.04	10.07	11.65	13.11	13.76	13.58	12.76	12.59	11.74	11.26	10.09	9.04	
T_{max}	23.46	24.72	25.60	26.22	27.23	27.57	23.64	23.06	24.84	24.04	22.99	22.76	
T_{mean}	16.25	17.39	18.62	19.67	20.49	20.57	18.20	17.82	18.29	17.65	16.54	15.90	
RH_{mean}	60.61	52.27	56.55	52.91	44.97	51.73	77.03	81.61	60.52	55.88	55.84	57.83	
Us in (m/s)	3.39	3.88	3.90	3.87	3.09	2.12	1.94	1.63	1.78	3.05	3.52	3.64	
Us in (Mile/day)	182.04	208.22	209.16	208.02	165.66	113.64	104.18	87.26	95.47	163.55	188.85	195.41	
$e^o (T_{min})$=0.60108(17.27T_{min}/T_{min}+237.3)	2.50	2.63	2.85	3.08	3.19	3.16	3.02	3.00	2.87	2.80	2.63	2.50	
$e^o (T_{max})$=0.60108(17.27T_{max}/T_{max}+237.3)	5.34	5.71	5.99	6.19	6.53	6.64	5.39	5.23	5.75	5.51	5.21	5.14	
Es=eo (Tmin)+eo (Tmax)/2	3.92	4.17	4.42	4.63	4.86	4.90	4.21	4.11	4.31	4.15	3.92	3.82	
e_d=RH_{mean}/100($e_o(T_{min})$+e_o (T_{max})/2)	2.37	2.18	2.50	2.45	2.18	2.54	3.24	3.36	2.61	2.32	2.19	2.21	
Vapour pressure deficit (es-ed)	1.54	1.99	1.92	2.18	2.67	2.37	0.97	0.76	1.70	1.83	1.73	1.61	
Ea=0.35*((0.5+U2)/100)*(es-ed)	0.99	1.45	1.41	1.59	1.55	0.95	0.35	0.23	0.57	1.05	1.15	1.10	
Δ (KPa/^{o}C)	0.12	0.13	0.11	0.14	0.15	0.15	0.13	0.13	0.13	0.13	0.12	0.12	
g	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Δ/ g	2.23	2.42	2.12	2.71	2.87	2.87	2.50	2.50	2.56	2.42	2.29	2.23	
dT_a^4 MJ $m^{-2}d^{-1}$	34.52	35.24	35.31	35.37	35.42	35.42	35.29	35.26	35.29	35.25	35.19	35.16	
dT_a^4 (mm/d)	14.09	14.38	14.41	14.44	14.46	14.46	14.40	14.39	14.40	14.39	14.36	14.35	
Ra (Norther hemisp here,14^o 00) MJ $m^{-2}d^{-1}$	29.90	33.10	36.10	38.10	38.40	38.10	38.10	38.00	36.70	33.90	30.60	28.90	
Ra (mm/day)	12.20	13.51	14.73	15.55	15.67	15.55	15.55	15.51	14.98	13.84	12.49	11.80	
N	9.49	9.54	9.03	9.24	9.78	7.67	5.34	5.37	8.29	9.39	9.76	9.79	
N (Norther hemisp here,14^o 00)	11.40	11.60	11.90	12.30	12.60	12.80	12.80	12.50	12.10	11.70	11.30	11.20	
R (Albedo)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
R1(1-r)=0.95Ra(0.18+0.55n/N)	7.40	8.11	8.36	8.76	9.04	7.53	6.05	6.13	7.93	8.17	7.77	7.41	
Ro=dT_K^d(0.56-0.09*$ed^{1/2}$)*(0.1+0.9*n/N)	5.04	5.16	4.71	4.70	4.93	3.85	2.73	2.77	4.28	5.00	5.38	5.42	
H=R_1(1-r)-R_o	2.35	2.95	3.65	4.07	4.11	3.68	3.32	3.37	3.64	3.16	2.39	1.98	
Eo=Δ/g(H)+Ea/Δ/g +1 (in mm/day)	1.93	2.52	2.93	3.40	3.45	2.97	2.48	2.47	2.78	2.55	2.01	1.71	
Evol=Eo*No day*A/1000 in m^3)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.01	6.39	3.81	1.59	**23.80**

Table C.2. Estimation of monthly evaporation loss by Penman combination method (Lemlem kahessay pond)

Month	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**total**
No of days in the month	31	28	31	30	31	30	31	31	30	31	30	31	
Pond surface area (A in $M^{2)}$									144.00	68.00	49.00	37.00	
T_{min}	9.04	10.07	11.65	13.11	13.76	13.58	12.76	12.59	11.74	11.26	10.09	9.04	
T_{max}	23.46	24.72	25.60	26.22	27.23	27.57	23.64	23.06	24.84	24.04	22.99	22.76	
T_{mean}	16.25	17.39	18.62	19.67	20.49	20.57	18.20	17.82	18.29	17.65	16.54	15.90	
RH_{mean}	60.61	52.27	56.55	52.91	44.97	51.73	77.03	81.61	60.52	55.88	55.84	57.83	
Us in (m/s)	3.39	3.88	3.90	3.87	3.09	2.12	1.94	1.63	1.78	3.05	3.52	3.64	
Us in (Mile/day)	182.04	208.22	209.16	208.02	165.66	113.64	104.18	87.26	95.47	163.55	188.85	195.41	
$e^o(T_{min})=0.60108(17.27T_{min}/T_{min}+237.3)$	2.50	2.63	2.85	3.08	3.19	3.16	3.02	3.00	2.87	2.80	2.63	2.50	
$e^o(T_{max})=0.60108(17.27T_{max}/T_{max}+237.3)$	5.34	5.71	5.99	6.19	6.53	6.64	5.39	5.23	5.75	5.51	5.21	5.14	
Es=eo (Tmin)+eo (Tmax)/2	3.92	4.17	4.42	4.63	4.86	4.90	4.21	4.11	4.31	4.15	3.92	3.82	
$e_d=RH_{mean}/100(e_o(T_{min})+e_o(T_{max})/2)$	2.37	2.18	2.50	2.45	2.18	2.54	3.24	3.36	2.61	2.32	2.19	2.21	
Vapour pressure deficit (es-ed)	1.54	1.99	1.92	2.18	2.67	2.37	0.97	0.76	1.70	1.83	1.73	1.61	
Ea=0.35*((0.5+U2)/100)*(es-ed)	0.99	1.45	1.41	1.59	1.55	0.95	0.35	0.23	0.57	1.05	1.15	1.10	
Δ (KPa/°C)	0.12	0.13	0.11	0.14	0.15	0.15	0.13	0.13	0.13	0.13	0.12	0.12	
g	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Δ/ g	2.23	2.42	2.12	2.71	2.87	2.87	2.50	2.50	2.56	2.42	2.29	2.23	
dT_a^4 MJ $m^{-2}d^{-1}$	34.52	35.24	35.31	35.37	35.42	35.42	35.29	35.26	35.29	35.25	35.19	35.16	
dT_a^4 (mm/d)	14.09	14.38	14.41	14.44	14.46	14.46	14.40	14.39	14.40	14.39	14.36	14.35	
Ra (Norther hemisp here,14° 00) MJ $m^{-2}d^{-1}$	29.90	33.10	36.10	38.10	38.40	38.10	38.10	38.00	36.70	33.90	30.60	28.90	
Ra (mm/day)	12.20	13.51	14.73	15.55	15.67	15.55	15.55	15.51	14.98	13.84	12.49	11.80	
N	9.49	9.54	9.03	9.24	9.78	7.67	5.34	5.37	8.29	9.39	9.76	9.79	
N (Norther hemisp here,14° 00)	11.40	11.60	11.90	12.30	12.60	12.80	12.80	12.50	12.10	11.70	11.30	11.20	
r (Albedo)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
R1(1-r)=0.95Ra(0.18+0.55n/N)	7.40	8.11	8.36	8.76	9.04	7.53	6.05	6.13	7.93	8.17	7.77	7.41	
$Ro=dT_K^d(0.56-0.09*ed^{1/2})*(0.1+0.9*n/N)$	5.04	5.16	4.71	4.70	4.93	3.85	2.73	2.77	4.28	5.00	5.38	5.42	
$H=R_1(1-r)-R_o$	2.35	2.95	3.65	4.07	4.11	3.68	3.32	3.37	3.64	3.16	2.39	1.98	
Eo=Δ/g(H)+Ea/Δ/g +1 (in mm/day)	1.93	2.52	2.93	3.40	3.45	2.97	2.48	2.47	2.78	2.55	2.01	1.71	
Evol=Eo*No day*A/1000 in m^3)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.01	5.37	2.96	1.96	**22.30**

Table C.3. Estimation of monthly evaporation loss by Penman combination method (Hagos Amare pond)

Month	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
No of days in the month	31	28	31	30	31	30	31	31	30	31	30	31	
Pond surface area (A in $M^{2)}$									144.00	42.00	23.00	12.00	
T_{min}	9.04	10.07	11.65	13.11	13.76	13.58	12.76	12.59	11.74	11.26	10.09	9.04	
T_{max}	23.46	24.72	25.60	26.22	27.23	27.57	23.64	23.06	24.84	24.04	22.99	22.76	
T_{mean}	16.25	17.39	18.62	19.67	20.49	20.57	18.20	17.82	18.29	17.65	16.54	15.90	
RH_{mean}	60.61	52.27	56.55	52.91	44.97	51.73	77.03	81.61	60.52	55.88	55.84	57.83	
Us in (m/s)	3.39	3.88	3.90	3.87	3.09	2.12	1.94	1.63	1.78	3.05	3.52	3.64	
Us in (Mile/day)	182.04	208.22	209.16	208.02	165.66	113.64	104.18	87.26	95.47	163.55	188.85	195.41	
$e^o (T_{min})=0.60108(17.27T_{min}/T_{min}+237.3)$	2.50	2.63	2.85	3.08	3.19	3.16	3.02	3.00	2.87	2.80	2.63	2.50	
$e^o (T_{max})=0.60108(17.27T_{max}/T_{max}+237.3)$	5.34	5.71	5.99	6.19	6.53	6.64	5.39	5.23	5.75	5.51	5.21	5.14	
Es=eo (Tmin)+eo (Tmax)/2	3.92	4.17	4.42	4.63	4.86	4.90	4.21	4.11	4.31	4.15	3.92	3.82	
$e_d=RH_{mean}/100(e_o(T_{min})+e_o (T_{max})/2)$	2.37	2.18	2.50	2.45	2.18	2.54	3.24	3.36	2.61	2.32	2.19	2.21	
Vapour pressure deficit (es-ed)	1.54	1.99	1.92	2.18	2.67	2.37	0.97	0.76	1.70	1.83	1.73	1.61	
Ea=0.35*((0.5+U2)/100)*(es-ed)	0.99	1.45	1.41	1.59	1.55	0.95	0.35	0.23	0.57	1.05	1.15	1.10	
Δ (KPa/^{o}C)	0.12	0.13	0.11	0.14	0.15	0.15	0.13	0.13	0.13	0.13	0.12	0.12	
g	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Δ/ g	2.23	2.42	2.12	2.71	2.87	2.87	2.50	2.50	2.56	2.42	2.29	2.23	
dT_a^4 MJ $m^{-2}d^{-1}$	34.52	35.24	35.31	35.37	35.42	35.42	35.29	35.26	35.29	35.25	35.19	35.16	
dT_a^4 (mm/d)	14.09	14.38	14.41	14.44	14.46	14.46	14.40	14.39	14.40	14.39	14.36	14.35	
Ra (Norther hemisp here,14^o 00) MJ $m^{-2}d^{-1}$	29.90	33.10	36.10	38.10	38.40	38.10	38.10	38.00	36.70	33.90	30.60	28.90	
Ra (mm/day)	12.20	13.51	14.73	15.55	15.67	15.55	15.55	15.51	14.98	13.84	12.49	11.80	
N	9.49	9.54	9.03	9.24	9.78	7.67	5.34	5.37	8.29	9.39	9.76	9.79	
N (Norther hemisp here,14^o 00)	11.40	11.60	11.90	12.30	12.60	12.80	12.80	12.50	12.10	11.70	11.30	11.20	
r (Albedo)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
R1(1-r)=0.95Ra(0.18+0.55n/N)	7.40	8.11	8.36	8.76	9.04	7.53	6.05	6.13	7.93	8.17	7.77	7.41	
$Ro=dT_K^d(0.56-0.09*ed^{1/2})*(0.1+0.9*n/N)$	5.04	5.16	4.71	4.70	4.93	3.85	2.73	2.77	4.28	5.00	5.38	5.42	
$H=R_1(1-r)-R_o$	2.35	2.95	3.65	4.07	4.11	3.68	3.32	3.37	3.64	3.16	2.39	1.98	
Eo=Δ/g(H)+Ea/Δ/g +1 (in mm/day)	1.93	2.52	2.93	3.40	3.45	2.97	2.48	2.47	2.78	2.55	2.01	1.71	
Evol=Eo*No day*A/1000 in m^3)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.01	3.32	1.39	0.64	**17.35**

Table C.4. Estimation of monthly evaporation loss by Penman combination method (Seyume wahide pond)

Month	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
No of days in the month	31	28	31	30	31	30	31	31	30	31	30	31	
Pond surface area (A in $M^{2)}$									177.00	39.00	31.00	20.00	
T_{min}	9.04	10.07	11.65	13.11	13.76	13.58	12.76	12.59	11.74	11.26	10.09	9.04	
T_{max}	23.46	24.72	25.60	26.22	27.23	27.57	23.64	23.06	24.84	24.04	22.99	22.76	
T_{mean}	16.25	17.39	18.62	19.67	20.49	20.57	18.20	17.82	18.29	17.65	16.54	15.90	
RH_{mean}	60.61	52.27	56.55	52.91	44.97	51.73	77.03	81.61	60.52	55.88	55.84	57.83	
Us in (m/s)	3.39	3.88	3.90	3.87	3.09	2.12	1.94	1.63	1.78	3.05	3.52	3.64	
Us in (Mile/day)	182.04	208.22	209.16	208.02	165.66	113.64	104.18	87.26	95.47	163.55	188.85	195.41	
e^{o} (T_{min})=0.60108(17.27T_{min}/T_{min}+237.3)	2.50	2.63	2.85	3.08	3.19	3.16	3.02	3.00	2.87	2.80	2.63	2.50	
e^{o} (T_{max})=0.60108(17.27T_{max}/T_{max}+237.3)	5.34	5.71	5.99	6.19	6.53	6.64	5.39	5.23	5.75	5.51	5.21	5.14	
Es=eo (Tmin)+eo (Tmax)/2	3.92	4.17	4.42	4.63	4.86	4.90	4.21	4.11	4.31	4.15	3.92	3.82	
e_d=RH_{mean}/100(e_o(T_{min})+e_o (T_{max})/2)	2.37	2.18	2.50	2.45	2.18	2.54	3.24	3.36	2.61	2.32	2.19	2.21	
Vapour pressure deficit (es-ed)	1.54	1.99	1.92	2.18	2.67	2.37	0.97	0.76	1.70	1.83	1.73	1.61	
Ea=0.35*((0.5+U2)/100)*(es-ed)	0.99	1.45	1.41	1.59	1.55	0.95	0.35	0.23	0.57	1.05	1.15	1.10	
Δ (KPa/^{o}C)	0.12	0.13	0.11	0.14	0.15	0.15	0.13	0.13	0.13	0.13	0.12	0.12	
g	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Δ/ g	2.23	2.42	2.12	2.71	2.87	2.87	2.50	2.50	2.56	2.42	2.29	2.23	
dT_a^{4} MJ $m^{-2}d^{-1}$	34.52	35.24	35.31	35.37	35.42	35.42	35.29	35.26	35.29	35.25	35.19	35.16	
dT_a^{4} (mm/d)	14.09	14.38	14.41	14.44	14.46	14.46	14.40	14.39	14.40	14.39	14.36	14.35	
Ra (Norther hemisp here,14^{o} 00) MJ $m^{-2}d^{-1}$	29.90	33.10	36.10	38.10	38.40	38.10	38.10	38.00	36.70	33.90	30.60	28.90	
Ra (mm/day)	12.20	13.51	14.73	15.55	15.67	15.55	15.55	15.51	14.98	13.84	12.49	11.80	
N	9.49	9.54	9.03	9.24	9.78	7.67	5.34	5.37	8.29	9.39	9.76	9.79	
N (Norther hemisp here,14^{o} 00)	11.40	11.60	11.90	12.30	12.60	12.80	12.80	12.50	12.10	11.70	11.30	11.20	
r (Albedo)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
R1(1-r)=0.95Ra(0.18+0.55n/N)	7.40	8.11	8.36	8.76	9.04	7.53	6.05	6.13	7.93	8.17	7.77	7.41	
Ro=dT_K^{d}(0.56-0.09*$ed^{1/2}$)*(0.1+0.9*n/N)	5.04	5.16	4.71	4.70	4.93	3.85	2.73	2.77	4.28	5.00	5.38	5.42	
H=R_1(1-r)-R_o	2.35	2.95	3.65	4.07	4.11	3.68	3.32	3.37	3.64	3.16	2.39	1.98	
Eo=Δ/g(H)+Ea/Δ/g +1 (in mm/day)	1.93	2.52	2.93	3.40	3.45	2.97	2.48	2.47	2.78	2.55	2.01	1.71	
Evol=Eo*No day*A/1000 in m^3)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.76	3.08	1.87	1.06	**20.78**

Table C.5. Estimation of monthly evaporation loss by Penman combination method (Haily Berhe pond)

Month	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
No of days in the month	31	28	31	30	31	30	31	31	30	31	30	31	
Pond surface area (A in $M^{2)}$									**156.00**	**101.00**	**86.00**	**55.00**	
T_{min}	9.04	10.07	11.65	13.11	13.76	13.58	12.76	12.59	11.74	11.26	10.09	9.04	
T_{max}	23.46	24.72	25.60	26.22	27.23	27.57	23.64	23.06	24.84	24.04	22.99	22.76	
T_{mean}	16.25	17.39	18.62	19.67	20.49	20.57	18.20	17.82	18.29	17.65	16.54	15.90	
RH_{mean}	60.61	52.27	56.55	52.91	44.97	51.73	77.03	81.61	60.52	55.88	55.84	57.83	
Us in (m/s)	3.39	3.88	3.90	3.87	3.09	2.12	1.94	1.63	1.78	3.05	3.52	3.64	
Us in (Mile/day)	182.04	208.22	209.16	208.02	165.66	113.64	104.18	87.26	95.47	163.55	188.85	195.41	
$e^o (T_{min})=0.60108(17.27T_{min}/T_{min}+237.3)$	2.50	2.63	2.85	3.08	3.19	3.16	3.02	3.00	2.87	2.80	2.63	2.50	
$e^o (T_{max})=0.60108(17.27T_{max}/T_{max}+237.3)$	5.34	5.71	5.99	6.19	6.53	6.64	5.39	5.23	5.75	5.51	5.21	5.14	
Es=eo (Tmin)+eo (Tmax)/2	3.92	4.17	4.42	4.63	4.86	4.90	4.21	4.11	4.31	4.15	3.92	3.82	
$e_d=RH_{mean}/100(e_o(T_{min})+e_o (T_{max})/2)$	2.37	2.18	2.50	2.45	2.18	2.54	3.24	3.36	2.61	2.32	2.19	2.21	
Vapour pressure deficit (es-ed)	1.54	1.99	1.92	2.18	2.67	2.37	0.97	0.76	1.70	1.83	1.73	1.61	
Ea=0.35*((0.5+U2)/100)*(es-ed)	0.99	1.45	1.41	1.59	1.55	0.95	0.35	0.23	0.57	1.05	1.15	1.10	
Δ (KPa/^{o}C)	0.12	0.13	0.11	0.14	0.15	0.15	0.13	0.13	0.13	0.13	0.12	0.12	
g	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Δ/ g	2.23	2.42	2.12	2.71	2.87	2.87	2.50	2.50	2.56	2.42	2.29	2.23	
dT_a^4 MJ $m^{-2}d^{-1}$	34.52	35.24	35.31	35.37	35.42	35.42	35.29	35.26	35.29	35.25	35.19	35.16	
dT_a^4 (mm/d)	14.09	14.38	14.41	14.44	14.46	14.46	14.40	14.39	14.40	14.39	14.36	14.35	
Ra (Norther hemisp here,14^o 00) MJ $m^{-2}d^{-1}$	29.90	33.10	36.10	38.10	38.40	38.10	38.10	38.00	36.70	33.90	30.60	28.90	
Ra (mm/day)	12.20	13.51	14.73	15.55	15.67	15.55	15.55	15.51	14.98	13.84	12.49	11.80	
N	9.49	9.54	9.03	9.24	9.78	7.67	5.34	5.37	8.29	9.39	9.76	9.79	
N (Norther hemisp here,14^o 00)	11.40	11.60	11.90	12.30	12.60	12.80	12.80	12.50	12.10	11.70	11.30	11.20	
r (Albedo)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
R1(1-r)=0.95Ra(0.18+0.55n/N)	7.40	8.11	8.36	8.76	9.04	7.53	6.05	6.13	7.93	8.17	7.77	7.41	
$Ro=dT_K^d(0.56-0.09*ed^{1/2})*(0.1+0.9*n/N)$	5.04	5.16	4.71	4.70	4.93	3.85	2.73	2.77	4.28	5.00	5.38	5.42	
$H=R_1(1-r)-R_o$	2.35	2.95	3.65	4.07	4.11	3.68	3.32	3.37	3.64	3.16	2.39	1.98	
Eo=Δ/g(H)+Ea/Δ/g +1 (in mm/day)	1.93	2.52	2.93	3.40	3.45	2.97	2.48	2.47	2.78	2.55	2.01	1.71	
Evol=Eo*No day*A/1000 in m^3)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.01	7.97	5.20	2.92	**29.10**

Table C.6. Estimation of monthly evaporation loss by Penman combination method (Hadish Mebratume pond)

Month	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
No of days in the month	31	28	31	30	31	30	31	31	30	31	30	31	
Pond surface area (A in M$^{2)}$									**132.00**	**92.00**	**78.00**	**65.00**	
T_{min}	9.04	10.07	11.65	13.11	13.76	13.58	12.76	12.59	11.74	11.26	10.09	9.04	
T_{max}	23.46	24.72	25.60	26.22	27.23	27.57	23.64	23.06	24.84	24.04	22.99	22.76	
T_{mean}	16.25	17.39	18.62	19.67	20.49	20.57	18.20	17.82	18.29	17.65	16.54	15.90	
RH_{mean}	60.61	52.27	56.55	52.91	44.97	51.73	77.03	81.61	60.52	55.88	55.84	57.83	
Us in (m/s)	3.39	3.88	3.90	3.87	3.09	2.12	1.94	1.63	1.78	3.05	3.52	3.64	
Us in (Mile/day)	182.04	208.22	209.16	208.02	165.66	113.64	104.18	87.26	95.47	163.55	188.85	195.41	
$e^o(T_{min})=0.60108(17.27T_{min}/T_{min}+237.3)$	2.50	2.63	2.85	3.08	3.19	3.16	3.02	3.00	2.87	2.80	2.63	2.50	
$e^o(T_{max})=0.60108(17.27T_{max}/T_{max}+237.3)$	5.34	5.71	5.99	6.19	6.53	6.64	5.39	5.23	5.75	5.51	5.21	5.14	
Es=eo (Tmin)+eo (Tmax)/2	3.92	4.17	4.42	4.63	4.86	4.90	4.21	4.11	4.31	4.15	3.92	3.82	
$e_d=RH_{mean}/100(e_o(T_{min})+e_o(T_{max})/2)$	2.37	2.18	2.50	2.45	2.18	2.54	3.24	3.36	2.61	2.32	2.19	2.21	
Vapour pressure deficit (es-ed)	1.54	1.99	1.92	2.18	2.67	2.37	0.97	0.76	1.70	1.83	1.73	1.61	
Ea=0.35*((0.5+U2)/100)*(es-ed)	0.99	1.45	1.41	1.59	1.55	0.95	0.35	0.23	0.57	1.05	1.15	1.10	
Δ (KPa/^{o}C)	0.12	0.13	0.11	0.14	0.15	0.15	0.13	0.13	0.13	0.13	0.12	0.12	
g	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
Δ/ g	2.23	2.42	2.12	2.71	2.87	2.87	2.50	2.50	2.56	2.42	2.29	2.23	
dT_a^4 MJ $m^{-2}d^{-1}$	34.52	35.24	35.31	35.37	35.42	35.42	35.29	35.26	35.29	35.25	35.19	35.16	
dT_a^4 (mm/d)	14.09	14.38	14.41	14.44	14.46	14.46	14.40	14.39	14.40	14.39	14.36	14.35	
Ra (Norther hemisp here,14^o 00) MJ $m^{-2}d^{-1}$	29.90	33.10	36.10	38.10	38.40	38.10	38.10	38.00	36.70	33.90	30.60	28.90	
Ra (mm/day)	12.20	13.51	14.73	15.55	15.67	15.55	15.55	15.51	14.98	13.84	12.49	11.80	
N	9.49	9.54	9.03	9.24	9.78	7.67	5.34	5.37	8.29	9.39	9.76	9.79	
N (Norther hemisp here,14^o 00)	11.40	11.60	11.90	12.30	12.60	12.80	12.80	12.50	12.10	11.70	11.30	11.20	
R (Albedo)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	
R1(1-r)=0.95Ra(0.18+0.55n/N)	7.40	8.11	8.36	8.76	9.04	7.53	6.05	6.13	7.93	8.17	7.77	7.41	
Ro=dT_K^d(0.56-0.09*$ed^{1/2}$)*(0.1+0.9*n/N)	5.04	5.16	4.71	4.70	4.93	3.85	2.73	2.77	4.28	5.00	5.38	5.42	
H=R_1(1-r)-R_o	2.35	2.95	3.65	4.07	4.11	3.68	3.32	3.37	3.64	3.16	2.39	1.98	
Eo=Δ/g(H)+Ea/Δ/g +1 (in mm/day)	1.93	2.52	2.93	3.40	3.45	2.97	2.48	2.47	2.78	2.55	2.01	1.71	
Evol=Eo*No day*A/1000 in m^3)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.01	7.26	4.71	3.45	**26.43**

APPENDIX D .Soil profile description from the targeted homegarden

Table D.1. Profile description of HagosAmare Backyard

Parameters		Depth			
		0-15cm	15-45cm	45-100cm	>100cm
Soil color	Dry	7.5YR 4/1 Dark gray	7.5YR 3/1 Very Dark gray	7.5YR 3/1 Very Dark gray	7.5YR 3/1 Very Dark gray
	Moist	7.5YR 3/1 Very Dark gray	7.5YR 2.5/1 Black	7.5YR2.5/1 Black	7.5YR 2.5/1 Black
Soil structure		Medium angular blocky	Medium sub angular blocky	Course sub angular blocky	Course sub angular blocky
Soil consistency	Dry	Extremely hard	Extremely hard	Extremely hard	Extremely hard
	Moist	Firm	Firm	Very firm	Very firm
Rooting condition		Abundant	Many	Few	Few
Macro Porosity		Fine	Very fine	Very fine	Very fine
Calcium carbonate content		Slight calcareous	Slight calcareous	Slight calcareous	Slight calcareous
Stoniness		Stone less	Stone less	Stone less	Stone less

Table D.2. Profile description of Hadish Mebrataom Backyard

Parameters		Depth			
		0-15cm	15-45cm	45-100cm	>100cm
Soil color	Dry	10YR5/1 Gray	10YR5/1 Grayish brown	10YR5/1 Grayish brown	10YR5/1 Grayish brown
	Moist	10YR3/1 Very dark gray	10YR4/2 dark grayish Brown	10YR5/3 Brown	10YR5/3 Brown
Soil structure		Medium granular	Medium granular	Course granular	Course granular
Soil consistency	Dry	Soft	Soft	Soft	Soft
	Moist	Very friable	Very friable	Very friable	Very friable
Rooting condition		Abundant	Many	Few	Few
Macro Porosity		Medium	Medium	Medium	Medium
Calcium carbonate content		Non calcareous	Non calcareous	Non calcareous	Non calcareous
Stoniness		Stone less	Stone less	Stone less	Stone less

Table D.3. Profile description of Hadish Mebrataom Backyard

Parameters		Depth			
		0-15cm	15-45cm	45-100cm	>100cm
Soil color	Dry	10YR 5/2 grayish brown	10YR 5/2 grayish brown	10YR 5/2 grayish brown	10YR 4/2 Dark grayish brown
	Moist	10YR 5/3 brown	10YR 5/3 brown	10YR 5/3 brown	10YR 3/3 Dark brown
Soil structure		Medium Crumb	Fine prismatic	Medium prismatic	Medium prismatic
Soil consistency	Dry	Slightly hard	Slightly hard	Hard	Hard
	Moist	Friable	Friable	Friable	Firm
Rooting condition		Many	Many	Few	Few
Macro Porosity		Medium	Medium	Fine	Fine
Calcium carbonate		Non calcareous	Non calcareous	Non calcareous	Non calcareous
Stoniness		Very slightly stony	Slightly stony	Slightly	Moderately stony

Table D.4. Profile description of Seyum Wahid Backyard

Parameters		Depth			
		0-15cm	15-45cm	45-100cm	>100cm
Soil color	Dry	7.5YR 4/3	7.5YR 7/4	7.5YR 8/1	7.5YR 4/3
	Moist	7.5YR 4/6 Strong brown	7.5YR 6/3 light brown	7.5YR 7/1 light brown	7.5YR 3/4Dark brown
Soil structure		Fine granular	Angular blocky	Angular blocky	Thick platy
Soil consistency	Dry	Hard	Hard	Very hard	Very hard
	Moist	Friable	Friable	Firm	Firm
Rooting condition		Many	Many	Few	Few
Macro Porosity		Medium	Fine	Fine	very fine
Calcium carbonate content		Calcareous	Very calcareous	Calcareous	Calcareous
Stoniness		stone less	few stones	few stones	common stones

Table D.5. Profile description of Amare Teare Backyard

Parameters		Depth			
		0-15cm	15-45cm	45-100cm	>100cm
Soil color	Dry	5YR4/2 Dark radish grassy	5YR4/2 Dark radish grassy	5YR4/2 Dark radish grassy	5YR4/2 Radish grassy
	Moist	5YR3/2 Dark radish greasy	5YR3/2 Dark radish greasy	5YR3/2 Dark radish grassy	5YR3/2 Dark radish greasy
Soil structure		Medium platy	Medium platy	Course Blocky	Course Blocky
Soil consistency	Dry	Hard	Hard	Very hard	Very hard
	Moist	Friable	Friable	Firm	Firm
Rooting condition		Many	Common	Few	Few
Macro Porosity		Course	Course	Medium	Medium
Calcium carbonate		Non calcareous	Non calcareous	Non calcareous	Non calcareous
Stoniness					

Table D.6. Profile description of Lemlem kahessay Backyard

Parameters		Depth			
		0-15cm	15-45cm	45-100cm	>100cm
Soil color	Dry	7.5YR5/2 Brown	7.5YR 5/2 Brown	7.5YR 4/2 Brown	7.5YR 4/2 Brown
	Moist	7.5YR 4/2 Brown	7.5YR 4/2 Brown	7.5YR 3/3 Dark Brown	7.5YR 3/2 Dark Brown
Soil structure		Structures less	structure less	medium blocky	medium blocky
Soil consistency	Dry	Loose	Loose	Very hard	Very hard
	Moist	Loose	Loose	Friable	Friable
Rooting condition	Many	Many	Common	Few	Few
Macro Porosity		Very Course	Very Course	Medium	Fine
Calcium carbonate content		Non calcareous	Non calcareous	Non calcareous	Non calcareous
Stoniness		Very slightly stony	Very slightly stony	Very slightly stony	Slightly stony

APPENDIX E. Daily water utilization record from the targeted six ponds

Table E.1. Daily water utilization record (Amare Taere Pond)

Date	Daily water level(m) H	B1	b2	S1	S2	Volume of existing water(M^3) W_{in}	Total utilized water(m3)	Types of water use: Irrigating trees(M^3) IRR_t	Irrigating vegetables(M^3) IRR_v	water lost by evaporation(m^3) Evo
initial water level	2.7	11.75	4.5	138.06	20.25	195.36				
15/03/97	1.6	9.3	4.5	86.49	20.25	98.78	96.58	**38.20**	**32.03**	**12.01**
17/03/97	1.5	9	4.5	81.00	20.25	91.13	7.65	4.32	3.33	
19/03/97	1.4	8.7	4.5	75.69	20.25	83.92	7.20	4.07	3.13	
21/03/97	1.35	8.55	4.5	73.10	20.25	80.48	3.44	1.94	1.50	
23/03/97	1.3	8.4	4.5	70.56	20.25	77.15	3.33	1.88	1.45	
25/03/97	1.25	8.25	4.5	68.06	20.25	73.92	3.23	1.82	1.40	
27/03/97	1.2	8.1	4.5	65.61	20.25	70.79	3.13	1.77	1.36	
29/03/97	1.15	7.95	4.5	63.20	20.25	67.77	3.03	1.71	1.32	
								17.52	**13.49**	**6.39**
1/4/1997	1.1	7.8	4.5	60.84	20.25	64.83	2.93	1.66	1.28	
6/4/1997	0.95	7.35	4.5	54.02	20.25	56.59	8.24	4.65	3.58	
11/4/1997	0.85	7.05	4.5	49.70	20.25	51.54	5.05	2.85	2.20	
17/04/97	0.7	6.6	4.5	43.56	20.25	44.59	6.96	3.93	3.03	
21/04/97	0.6	6.3	4.5	39.69	20.25	40.34	4.25	2.40	1.85	
26/04/97	0.5	6	4.5	36.00	20.25	36.38	3.96	2.24	1.72	
								17.74	**13.65**	**3.81**
1/5/1997	0.4	5.7	4.5	32.49	20.25	32.68	3.69	2.09	1.61	
6/5/1997	0.35	5.55	4.5	30.80	20.25	30.93	1.75	0.99	0.76	
11/5/1997	0.35	5.55	4.5	30.80	20.25	30.93	0.00	0.00	0.00	
16/5/1997	0.3	5.4	4.5	29.16	20.25	29.24	1.69	0.95	0.74	
								4.03	**3.10**	**1.5**
Total							**166.12**	**77.49**	**62.28**	**23.71**

Table E.2. Daily water utilization record (Hagos Amare Pond)

Date	Daily water level(m)	B1	b2	S1	S2	Volume of existing water(M^3)	Water utilization and loss in (m3)	Types of water use: Irrigating trees(M^3) IRR_t	Irrigating vegetables(M^3) IRR_v	Volume Occupied by sediment(M3)	The estimated water lost by evaporation(m3) Evo
Initial depth	2.8	12	3	144.00	9	178.8	98.54	53.63	40.04		
19/2/97	1.45	7.35	3	54.02	9	52.51	3.99	1.15	3		
21/2/97	1.37	7.11	3	50.55	9	48.53	4.20	1.1	2.5		
24/2/97	1.28	6.84	3	46.79	9	44.32	1.78	1	3		
27/2/97	1.24	6.72	3	45.16	9	42.55	2.56	1.152	3.5		
Sub total							**111.07**	**4.402**	**12**		
1/3/1997	1.18	6.54	3	42.77	9	39.98	3.23	1.152	2.52		
4/3/1997	1.1	6.3	3	39.69	9	36.75	1.92	1.152	2		
12/3/1997	1.05	6.15	3	37.82	9	34.84	1.84	1.152			
14/3/97	1	6	3	36.00	9	33.00	2.45	1.152	0.05		
18/3/97	0.93	5.79	3	33.52	9	30.55	2.94	0.4			
21/3/97	0.84	5.52	3	30.47	9	27.61	1.24	0.8	0.05		
23/3/97	0.8	5.4	3	29.16	9	26.38	2.91	0.6	0.1		
27/3/97	0.7	5.1	3	26.01	9	23.47	2.66	1.152	0.15		
Sub total							19.18	**7.56**	**4.87**		
1/4/1997	0.6	4.8	3	23.04	9	20.81	1.24	1.152	0.05		
5/4/1997	0.55	4.65	3	21.62	9	19.56	1.19	1.152			
12/4/1997	0.5	4.5	3	20.25	9	18.38	0.46	1.152	0.1		
15/4/97	0.48	4.44	3	19.71	9	17.91	0.45	0.8	0.05		
18/4/97	0.46	4.38	3	19.18	9	17.46	0.44	0.35			
21/4/97	0.44	4.32	3	18.66	9	17.02	0.87	0.4			
25/4/97	0.4	4.2	3	17.64	9	16.15	1.24	0.9			
28/4/97	0.34	4.02	3	16.16	9	14.91	2.29	1.152			
Sub total							**8.19**	**7.058**	**0.2**		
3/5/1997	0.22	3.66	3	13.40	9	12.62	1.23	1.152			
6/5/1997	0.15	3.45	3	11.90	9	11.40	1.16	0.85			
10/5/1997	0.08	3.24	3	10.50	9	10.24	0.47	1			
13/05/97	0.05	3.15	3	9.92	9	9.77	9.77	0.5			
Sub total							**12.62**	**3.502**			
Total							**151.05**	**76.15**	**57.11**	**0.441**	**17.35**

Table E.3. Daily water utilization record (Seyum Wahid Pond)

Date	Daily water level(m)	B1	b2	S1	S2	Volume of existing water(M^3) W_{in}	Total utilized & lost water(m 3)	Types of water use: Irrigating trees(M^3) IRR_t	Irrigating vegetables(M^3) IRR_v	For livestock's(M3) LV	Volume Occupied by sediment(M3)	The water lost by evaporation(m3) Evo	Seepage loss(m3)
Initial water level	3	13.3	3.2	176.89	10.2	229.69							
22/02/97	1.15	7.95	3.2	63.20	10.2	37.90	191.79	46.03	47.95	46.03			
25/02/97	0.85	7.05	3.2	49.70	10.2	23.38	14.53	1.50	0.50	1.00			
28/02/97	0.65	6.45	3.2	41.60	10.2	15.70	7.67	2.00	3.50	1.00			
Sub total								**49.53**	**51.95**	**48.03**			
1/3/1997	0.6	6.3	3.2	39.69	10.2	14.02	1.69	1.00	0.40	1.50			
4/3/1997	0.56	6.18	3.2	38.19	10.2	12.73	1.29	1.20	1.80	0.80			
15/03/97	0.5	6	3.2	36.00	10.2	10.91	1.83	0.50	0.70	1.00			
17/03/97	0.45	5.85	3.2	34.22	10.2	9.48	1.43	0.40	0.30	0.00			
20/03/97	0.43	5.79	3.2	33.52	10.2	8.93	0.55	0.30	0.25	0.45			
23/03/97	0.42	5.76	3.2	33.18	10.2	8.66	0.27	0.28	0.25	0.43			
26/03/97	0.41	5.73	3.2	32.83	10.2	8.39	0.27	0.26	0.25	0.42			
29/03/97	0.4	5.7	3.2	32.49	10.2	8.13	0.26	0.26	0.25	0.42			
Sub total								**4.20**	**4.19**	**5.02**			
2/4/1997	0.36	5.58	3.2	31.14	10.2	7.11	1.02	0.25	0.22	0.42			
5/4/1997	0.3	5.4	3.2	29.16	10.2	5.67	1.44	0.25	0.24	0.41			
8/4/1997	0.2	5.1	3.2	26.01	10.2	3.50	2.16	0.23	0.22	0.35			
11/4/1997	0.15	4.95	3.2	24.50	10.2	2.53	0.98	0.22	0.21	0.31			
14/04/97	0.1	4.8	3.2	23.04	10.2	1.62	0.91	0.18	0.20	0.20			
17/04/97	0.05	4.65	3.2	21.62	10.2	0.78	0.84	0.16	0.18	0.18			
22/04/97	0	4.5	3.2	20.25	10.2	0.00	0.78	0.12	0.10	0.15			
Sub total								**1.41**	**1.37**	**2.02**			
							229.69	**55.14**	**57.51**	**55.07**	**0.512**	**20.78**	**40.16**

Table E.4. Daily water utilization record (Haily Abrha Pond)

Date	Daily water level(m)	B1	b2	S1	S2	Volume of existing water(M^3) W_{in}	total utilized water(m3)	Types of water use: Irrigating trees(M^3) IRR_t	Irrigating vegetables(M^3) IRR_v	For livestock's(M3) LV	water lost by evaporation(m3) Evo
	2.2	12.5	5	156.25	20.3	185.68					
21/2/97	2	10.5	5	110.25	20.3	134.25	51.43	18.52	12.86	8.23	
24/2/97	1.95	10.35	5	107.12	20.3	129.37	4.88	1.76	1.22	0.78	
27/2/97	1.9	10.2	5	104.04	20.3	124.62	4.75	1.71	1.19	0.76	
Sub total							61.07	**21.98**	**15.27**	**9.77**	
30/2/97	1.85	10.05	5	101.00	20.3	120.00	4.62	1.66	1.15	0.74	
3/3/1997	1.8	9.9	5	98.01	20.3	115.51	4.49	1.62	1.12	0.72	
6/3/1997	1.7	9.6	5	92.16	20.3	106.90	8.61	3.10	2.15	1.38	
11/3/1997	1.68	9.54	5	91.01	20.3	105.24	1.66	0.60	0.42	0.27	
16/3/1997	1.65	9.45	5	89.30	20.3	102.78	2.46	0.88	0.61	0.39	
22/3/1997	1.6	9.3	5	86.49	20.3	98.78	4.00	1.44	1.00	0.64	
26/3/1997	1.58	9.24	5	85.38	20.3	97.21	1.57	0.56	0.39	0.25	
Sub total							27.41	**9.87**	**6.85**	**4.39**	
1/4/1997	1.55	9.15	5	83.72	20.3	94.89	2.32	0.83	0.58	0.37	
7/4/1997	1.53	9.09	5	82.63	20.3	93.37	1.52	0.55	0.38	0.24	
12/4/1997	1.5	9	5	81.00	20.3	91.13	2.25	0.81	0.56	0.36	
15/4/1997	1.48	8.94	5	79.92	20.3	89.65	1.48	0.53	0.37	0.24	
20/4/1997	1.45	8.85	5	78.32	20.3	87.47	2.18	0.79	0.55	0.35	
25/4/1997	1.4	8.7	5	75.69	20.3	83.92	3.55	1.28	0.89	0.57	
Sub total							13.29	**4.78**	**3.32**	**2.13**	
							101.76	**36.63**	**25.44**	**16.28**	**29.10**

Table E.5. Daily water utilization record (Lemlem Kahessay Pond)

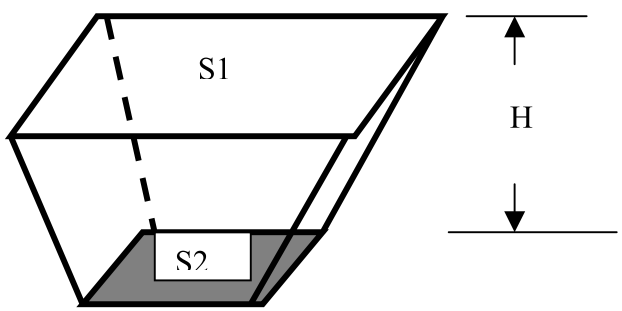
Date	Daily water level(m)=H	b1	b2	S1	S2	Volume of existing water(M^3) W_{in}	total utilized water(m3)	Types of water use			water lost by evaporation(m3) Evo
								Irrigating trees(M^3) IRR_t	Irrigating vegetables(M^3) IRR_v	For livestock's(M3) Ql	
initial water level	2.8	12	4.5	144	20.3	207.30					
15/03/97	1.75	9.75	4.5	95.0625	20.3	111.14	96.16	33.66	24.04	15.39	
17/03/97	1.65	9.45	4.5	89.3025	20.3	102.78	8.36	2.93	2.09	1.34	
19/03/97	1.55	9.15	4.5	83.7225	20.3	94.89	7.88	2.76	1.97	1.26	
21/03/97	1.5	9	4.5	81	20.3	91.13	3.77	1.32	0.94	0.60	
23/03/97	1.45	8.85	4.5	78.3225	20.3	87.47	3.66	1.28	0.91	0.59	
25/03/97	1.35	8.55	4.5	73.1025	20.3	80.48	6.98	2.44	1.75	1.12	
27/03/97	1.25	8.25	4.5	68.0625	20.3	73.92	6.56	2.30	1.64	1.05	
29/03/97	1.2	8.1	4.5	65.61	20.3	70.79	3.13	1.09	0.78	0.50	
Sub total								**14.12**	**10.09**	**6.46**	
1/4/1997	1.15	7.95	4.5	63.2025	20.3	67.77	3.03	1.06	0.76	0.48	
6/4/1997	0.95	7.35	4.5	54.0225	20.3	56.59	11.17	3.91	2.79	1.79	
11/4/1997	0.85	7.05	4.5	49.7025	20.3	51.54	5.05	1.77	1.26	0.81	
17/04/97	0.75	6.75	4.5	45.5625	20.3	46.83	4.72	1.65	1.18	0.75	
21/04/97	0.7	6.6	4.5	43.56	20.3	44.59	2.24	0.78	0.56	0.36	
26/04/97	0.6	6.3	4.5	39.69	20.3	40.34	4.25	1.49	1.06	0.68	
Sub total								**10.66**	**7.61**	**4.87**	
1/5/1997	0.55	6.15	4.5	37.8225	20.3	38.32	2.02	0.71	0.50	0.32	
Total								**59.14**	**42.24**	**27.04**	**22.30**

Table E.6. Daily water utilization record (Hadish Mebratom Pond)

Date	Daily water level(m)	B1	b2	S1	S2	Volume of existing water(M^3) W_{in}	Total utilized water(m3)	Types of water use			water lost by evaporation(m3) Evo
								Irrigating trees(M^3) IRR_t	Irrigating vegetables(M^3) IRR_v	For livestock's(M3) LV	
initial water level	2.7	11.5	5	132.25	20.3	189.00					
21/2/97	1.9	10.2	5	104.04	20.3	124.62	64.38	**24.47**	**19.31**	**5.15**	
24/2/97	1.85	10.05	5	101.00	20.3	120.00	4.62	1.76	1.39	0.37	
27/2/97	1.82	9.96	5	99.20	20.3	117.29	2.71	1.03	0.81	0.22	
30/2/97	1.8	9.9	5	98.01	20.3	115.51	1.78	0.68	0.53	0.14	
Sub total								**3.46**	**2.73**	**0.73**	
3/3/1997	1.77	9.81	5	96.24	20.3	112.87	2.63	1.00	0.79	0.21	
6/3/1997	1.75	9.75	5	95.06	20.3	111.14	1.73	0.66	0.52	0.14	
11/3/1997	1.7	9.6	5	92.16	20.3	106.90	4.24	1.61	1.27	0.34	
16/3/97	1.65	9.45	5	89.30	20.3	102.78	4.12	1.57	1.24	0.33	
22/3/97	1.62	9.36	5	87.61	20.3	100.36	2.41	0.92	0.72	0.19	
Sub total								**5.75**	**4.54**	**1.21**	
							88.64	**33.68**	**26.59**	**7.09**	**26.43**

Pond design and volume

$$W_{in} = H/3*(S_1+S_2)+\sqrt{S_1*S_2}$$



Where W_{in} is Volume of the pond
S1 is Top area of the pond
S2 is bottom area of the pond
H is Depth of the pond

APPENDIX F. Soil Moisture content at different section head apparatus

Table F.1 Results of sand box analysis

Tin Code	Initial mass of the soil	Mass at saturation	Mass at different pF				Mass of ring,tissue and rubber ring	Mass of sample after oven drying +ring	ρ_b	θ_v at pF 1	θ_m at pF 1	θ_v at pF 1.5	θ_m at pF 1.5	θ_v at pF 1.84	θ_m at pF 1.84	θ_v at pF 2	θ_m at pF 2
			pF=1	pF= 1.5	pF= 1.837	pF=2											
AT13	255	283.5	279	268.5	254.5	249.5	98.5	226	1.28	0.53	0.42	0.43	0.33	0.29	0.22	0.24	0.18
AT32	267	290.5	286	281.5	266	260.5	97.5	248.5	1.51	0.38	0.25	0.33	0.22	0.18	0.12	0.12	0.08
AT22	266	290.5	289.5	281	265.5	260.5	97	247	1.50	0.43	0.28	0.34	0.23	0.19	0.12	0.14	0.09
average	**262.67**	**288.17**	**284.83**	**277.00**	**262.00**	**256.83**	**97.67**	**240.50**	**1.43**	**0.44**	**0.31**	**0.37**	**0.26**	**0.22**	**0.15**	**0.16**	**0.11**
LK13	263	295.5	290.5	273.5	261.5	260	97	255	1.58	0.36	0.22	0.19	0.12	0.07	0.04	0.05	0.03
LK21	276	299.5	297	288	276.5	273	97.5	259.5	1.62	0.38	0.23	0.29	0.18	0.17	0.10	0.14	0.08
average	**269.50**	**297.50**	**293.75**	**280.75**	**269.00**	**266.50**	**97.25**	**257.25**	**1.60**	**0.37**	**0.23**	**0.24**	**0.15**	**0.12**	**0.07**	**0.09**	**0.06**
HA2	295	310	306.5	299.5	297.5	295.5	98	246	1.48	0.61	0.41	0.54	0.36	0.52	0.35	0.50	0.33
HA1	298	304	302	297.5	296	294.5	98	249	1.51	0.53	0.35	0.49	0.32	0.47	0.31	0.46	0.30
average	**296.5**	**307**	**304.25**	**298.5**	**296.75**	**295**	**98**	**247.5**	**1.50**	**0.57**	**0.38**	**0.51**	**0.34**	**0.49**	**0.33**	**0.48**	**0.32**
HM2	269	270	268.5	263	259	256.5	98	212	1.14	0.57	0.50	0.51	0.45	0.47	0.41	0.45	0.39
HM1	274	281.5	280	275.5	273.5	271.5	98	229	1.31	0.51	0.39	0.47	0.35	0.45	0.34	0.43	0.32
HM3	260	271.5	269.5	264	260.5	258.5	97	215.5	1.19	0.54	0.46	0.49	0.41	0.45	0.38	0.43	0.36
average	**267.67**	**274.33**	**272.67**	**267.50**	**264.33**	**262.17**	**97.67**	**218.83**	**1.21**	**0.54**	**0.44**	**0.49**	**0.40**	**0.46**	**0.38**	**0.43**	**0.36**
HB3	286	295	294	287.5	284.5	283	98	250	1.52	0.44	0.29	0.38	0.25	0.35	0.23	0.33	0.22
HB1	285	294.5	289.5	281	278	276	99	253	1.54	0.37	0.24	0.28	0.18	0.25	0.16	0.23	0.15
HB2	282	291	288.5	280	275.5	273.5	98	243.5	1.46	0.45	0.31	0.37	0.25	0.32	0.22	0.30	0.21
average	**284.33**	**293.50**	**290.67**	**282.83**	**279.33**	**277.50**	**98.33**	**248.83**	**1.51**	**0.42**	**0.28**	**0.34**	**0.23**	**0.31**	**0.20**	**0.29**	**0.19**
SW2	280	289	287	283.5	279	277.5	98	241	1.43	0.46	0.32	0.43	0.30	0.38	0.27	0.37	0.26
SW1	283	305.5	301	293	289	287.5	97	246.5	1.50	0.55	0.36	0.47	0.31	0.43	0.28	0.41	0.27
average	**281.50**	**297.25**	**294.00**	**288.25**	**284.00**	**282.50**	**97.50**	**243.75**	**1.46**	**0.50**	**0.34**	**0.45**	**0.30**	**0.40**	**0.28**	**0.39**	**0.26**

Table F.2 Results of pressure plate apparatus (Low pressure)

Tin Code	Mass befor saturation	Mass at saturation	mass at different pressure			Mass after oven dry	mass of ring, tissue and rubber ring	ρ_b	θ_v at pF 2.33	θ_m at pF 2.33	θ_v at pF 2.55	θ_m at pF 2.55	θ_v at pF 3.03	θ_m at pF 3.03
			0.2bar	0.3bar	1bar									
AT2	265	283.5	250	248.5	247.5	239.5	97.5	1.42	0.11	0.07	0.09	0.06	0.08	0.06
AT3	260.5	294.5	262.5	261	260.5	254	99	1.55	0.09	0.05	0.07	0.05	0.07	0.04
AT1	241.5	277	241	239.5	238	223.5	98.5	1.25	0.18	0.14	0.16	0.13	0.15	0.12
average	**255.67**	**285.00**	**251.17**	**249.67**	**248.67**	**239.00**	**98.33**	**1.41**	**0.12**	**0.09**	**0.11**	**0.08**	**0.10**	**0.07**
LK2	242.5	294	264.5	263.5	262	253.5	98.5	1.55	0.11	0.07	0.10	0.06	0.09	0.05
LK1	257.5	289.5	258.5	258	257.5	253	98.5	1.55	0.06	0.04	0.05	0.03	0.05	0.03
average	**250**	**291.75**	**261.5**	**260.75**	**259.75**	**253.25**	**98.5**	**1.55**	**0.08**	**0.05**	**0.08**	**0.05**	**0.07**	**0.04**
HM3	251	270.5	253.5	252	244	214	97.5	1.17	0.40	0.34	0.38	0.33	0.30	0.26
HM2	244.5	265.5	247	245	236	208.5	95	1.14	0.39	0.34	0.37	0.32	0.28	0.24
HM1	260	277	262	259	248	224	98.5	1.26	0.38	0.30	0.35	0.28	0.24	0.19
average	**251.83**	**271.00**	**254.17**	**252.00**	**242.67**	**215.50**	**97.00**	**1.19**	**0.39**	**0.33**	**0.37**	**0.31**	**0.27**	**0.23**
HB3	288.5	304	290	289	285.5	262	99	1.63	0.28	0.17	0.27	0.17	0.24	0.14
average	**288.5**	**304**	**290**	**289**	**285.5**	**262**	**99**	**1.63**	**0.28**	**0.17**	**0.27**	**0.17**	**0.24**	**0.14**
SW2	288.5	301.5	290	289	288	251	98	1.53	0.39	0.25	0.38	0.25	0.37	0.24
SW1	285.5	303.5	285.5	284	281	248	98.5	1.50	0.38	0.25	0.36	0.24	0.33	0.22
average	**287**	**302.5**	**287.75**	**286.5**	**284.5**	**249.5**	**98.25**	**1.51**	**0.38**	**0.25**	**0.37**	**0.24**	**0.35**	**0.23**
HA1	277.5	296	280	278.5	276.5	238	98	1.40	0.42	0.30	0.41	0.29	0.39	0.28
HA2	270.5	297	273	271.5	268.5	229.5	98	1.32	0.44	0.33	0.42	0.32	0.39	0.30
average	**274**	**296.5**	**276.5**	**275**	**272.5**	**233.75**	**98**	**1.36**	**0.43**	**0.31**	**0.41**	**0.30**	**0.39**	**0.29**

Table F.3 Results of pressure plate apparatus (High pressure)

Tin code	Ring code	sample code	Bulk density ρ_b	At 5bar Mass of Tin	Mass of Tin + dry before oven dry	Mass of Tin + dry after oven dry	θ_m at pF3.73	θ_v at pF 3.73	At 15bar Mass of Tin	Mass of Tin + dry before oven dry	Mass of Tin + dry after oven dry	θ_m at pF 4.2	θ_v at pF 4.2
14	3	AT1	1.28	13	38	36.68	0.06	0.07	13	42.5	41	0.05	0.07
15	4	AT1	1.28	12	37.5	36.06	0.06	0.08	13	41	39.57	0.05	0.07
16	5	AT2	1.5	13	33	32	0.05	0.08	13	40	38.21	0.07	0.11
33	6	AT2	1.5	13.5	35	34.33	0.03	0.05	13.5	43	41.83	0.04	0.06
37	7	AT3	1.51	13	34.5	32.85	0.08	0.13	13	40.5	38.8	0.07	0.10
48	8	AT3	1.51	13	34	32.47	0.08	0.12	13	38.5	36.94	0.07	0.10
Average			**1.43**	**12.92**	**35.33**	**34.07**	**0.06**	**0.09**	**13.08**	**40.92**	**39.39**	**0.06**	**0.08**
51	9	HM1	1.31	13.5	29.5	27.61	0.13	0.18	13.5	28.5	27.6	0.06	0.08
61	10	HM1	1.31	13	29	27.61	0.10	0.12	13	25	23.85	0.11	0.14
10	11	HM2	1.14	13	28	26.41	0.12	0.14	13.5	29.5	28.23	0.09	0.10
52	12	HM2	1.14	13	28	26.36	0.12	0.14	13.5	31.5	30.24	0.08	0.09
17	13	HM3	1.19	13	33	31.14	0.10	0.12	13.5	36.5	35.05	0.07	0.08
18	14	HM3	1.19	13	34	31.8	0.12	0.14	13.5	32.5	31.44	0.06	0.07
average			**1.21**	**13.08**	**30.25**	**28.49**	**0.11**	**0.14**	**13.42**	**30.58**	**29.40**	**0.07**	**0.09**
35	15	HB2	1.46	13	35	33.12	0.09	0.14	13.5	37	36.27	0.03	0.05
22	16	HB2	1.46	12.5	37	35.13	0.08	0.12	13	39	37.98	0.04	0.06
34	17	HB1	1.54	13.5	35	33.27	0.09	0.13	13.5	39.5	38.4	0.04	0.07
11	18	HB1	1.54	13	34	32.35	0.09	0.13	13	35	34.14	0.04	0.06
20	19	HB3	1.52	7	25	23.29	0.10	0.16	13	38.5	37.24	0.05	0.08
60	20	HB3	1.52	7	26.5	24.66	0.10	0.16	13	40	38.92	0.04	0.06
average			**1.51**	**11.00**	**32.08**	**30.30**	**0.09**	**0.14**	**13.17**	**38.17**	**37.16**	**0.04**	**0.06**
12	1	Lk1	1.58	12.5	43	42.55	0.01	0.02	12.5	42	41.71	0.01	0.02
8	2	LK1	1.58	13	41	40.5	0.02	0.03	13	43	42.62	0.01	0.02
263	1	LK2	1.62	13	44	43	0.03	0.05	3.5	26	25.5	0.02	0.04
264	2	LK2	1.62	13	46	45	0.03	0.05	3.5	29.5	29	0.02	0.03
265	3	LK3	1.6	13	48.5	46.5	0.06	0.10	3.5	16	15.5	0.04	0.07
266	4	LK3	1.6	13	48	46	0.06	0.10	3.5	28.5	27.5	0.04	0.07
average			**1.6**	**12.92**	**45.08**	**43.93**	**0.04**	**0.06**	**6.58**	**30.83**	**30.31**	**0.02**	**0.04**
36	5	HA1	1.28	13	36.5	32.5	0.21	0.26	13	30.5	28	0.17	0.21
21	6	HA1	1.28	13	36.5	32.5	0.21	0.26	13	31.5	28	0.23	0.30
2	7	HA2	1.5	13	41	35.5	0.24	0.37	13	29	26	0.23	0.35
23	8	HA2	1.5	13	41.5	36.5	0.21	0.32	13.5	31	28	0.21	0.31
6	9	HA3	1.51	13	39.5	34.5	0.23	0.35	14	35	31	0.24	0.36
5	10	HA3	1.51	13.5	38.5	34	0.22	0.33	13	31	27.5	0.24	0.36
average			**1.43**	**13.08**	**38.92**	**34.25**	**0.22**	**0.32**	**13.25**	**31.33**	**28.08**	**0.22**	**0.31**
1	11	SW1	1.5	12.5	35.5	32.5	0.15	0.23	6.5	28.5	25.5	0.16	0.24
2	12	SW1	1.5	13.5	40	36	0.18	0.27	6.5	28	26	0.10	0.15
3	13	SW2	1.43	14	43.5	40	0.13	0.19	6.5	27.5	25.5	0.11	0.15
4	14	SW2	1.43	13.5	41	37.5	0.15	0.21	7	29	26.5	0.13	0.18
5	15	SW3	1.46	13	41.5	36.5	0.21	0.31	7	26.5	23.5	0.18	0.27
6	16	SW3	1.46	13.5	39	34	0.24	0.36	7	27	23	0.25	0.37
average			**1.46**	**13.33**	**40.08**	**36.08**	**0.18**	**0.26**	**6.75**	**27.75**	**25.00**	**0.15**	**0.22**

APPENDIX G. Summarized data of crop type, cropping calendar, percentage area coverage and yield

Type of crop	Planting date	Unit cost in birr/kg	Lemlem Kahessay					Amarre Tarre					Hagos Amare				
			Area in m^2	%	Yield in Kg	in birr	Yield kg/ M^2	Area in m^2	%	Yield in Kg	in birr	Yield kg/ M^2	Area in m^2	%	Yield in Kg	in birr	Yield kg/ M^2
Cabbage	July20th	1.5	86	21	120	360	1.40	20	10.8	62	186	3.10		0		0	
Tomato	July 12th	1.13	136	34	0	0	0.00		0.0		0			0		0	
Pepper	July17th	5		0		0		20	10.8	28	140	1.40	229	89	125	625	0.55
Onion	July13th	2		0		0			0.0		0		10.5	4	10	20	0.95
Swiss chared	July20th	1.5	20	5	16	24	0.80	31	16.8	32	48	1.03		0		0	
Lettuce	July20th	1	65	16	82	82	1.26	38	20.5	28	28	0.74		0		0	
Carrot	July15th	1.5	50	12	42	63	0.84	34	18.4	38	57	1.12		0		0	
Potato	July10th	1.35		0		0		42	22.7		0		17.5	7	50	67.5	2.86
White cumin	July16th	5	20	5	8	40	0.40		0.0	28	37.8	0.67		0		0	
Black cumin	July16th	5	25	6	10	50	0.40		0.0		0			0		0	
Total			**402**	**100**	**356**	**697**		**185**	**100**	216	449.8		**257**	**100**	**185**	**713**	

b. Summarized data of crop type, cropping calendar, percentage area coverage and yield

Type of crop	Planting date	Unit cost in birr/kg	Seyume Wahid					Haily Aberhe					Hadish Mebratue				
			Area in m^2	%	Yield in Kg	in birr	Yield kg/ M^2	Area in m^2	%	Yield in Kg	in birr	Yield kg/ M^2	Area in m^2	%	Yield in Kg	in birr	Yield kg/ M^2
Cabbage	July20th	1.5	31	4	47	141	1.52		0.0		0		4	1.6	8	24	2
Tomato	July 12th	1.13		0		0		82	24.7	68	76.84	0.83	25	9.8	22.00	24.9	0.88
Pepper	July17th	5	191	18	105	525	0.55	220	66.3	250	1250	1.14	152	59.8	80	400	0.53
Onion	July13th	2	16	1	8	16	0.50		0.0		0			0.0		0	
Swiss chared	July20th	1.5		0		0			0.0		0		25	9.8	24	36	0.96
Sweet potato	July18th	1.5	63	9	70	105	1.11		0.0		0			0.0		0	
Potato	July10th	1.35	97	7	9	12.15	0.09		0.0		0			0.0		0	
White cumin	July16th	5	101	14	20	100	0.20		0.0		0			0.0		0	
Black cumin	July16th	5	162	23	30	150	0.19		0.0		0			0.0		0	
Cucumber	July12th	0.25		0		0		30	9.0	300	75	10.00		0.0		0	
Total			**661**	**76.66**	**289**	**1049**		**332**	**100**	**618**	**1402**		**206**	**81.1**	**134**	**485**	

APPENDIX H. Crop water requirement report computed by CropWat 4 Windows Software

5/1/2005 CropWat 4 Windows Ver 4.3

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Crop Water Requirements Report

****

- Crop # 1 : CABBAGE (Crucifers)
- Block # : [All blocks]
- Planting date : 20/7
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
20/7	45.52	4.00	0.03	1.27	1.82	1.41	0.00	0.00
30/7	44.55	4.00	0.03	1.25	2.28	1.66	0.00	0.00
9/8	43.75	4.00	0.03	1.25	2.47	1.72	0.00	0.00
19/8	43.14	4.00	0.03	1.39	2.06	1.40	0.00	0.00
29/8	42.72	4.00	0.04	1.55	0.68	0.47	1.08	0.02
8/9	42.48	4.00	0.04	1.71	0.00	0.00	1.71	0.03
18/9	42.43	4.00	0.04	1.78	0.00	0.00	1.78	0.03
28/9	42.54	4.00	0.04	1.79	0.00	0.00	1.79	0.03
8/10	42.79	4.00	0.04	1.78	0.00	0.00	1.78	0.03
18/10	43.16	4.00	0.04	1.69	0.00	0.00	1.69	0.03
Total	433.07			15.46	9.30	6.65	9.83	[0.02]

****

Crop Water Requirements Report (Amare Teare)

****

- Crop # 2 : Peppers
- Block # : [All blocks]
- Planting date : 17/7
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
17/7	45.10	11.00	0.07	2.98	4.88	3.65	0.00	0.00
27/7	44.14	11.00	0.07	2.91	7.07	4.66	0.00	0.00
6/8	43.36	11.00	0.07	2.86	8.76	5.29	0.00	0.00
16/8	42.78	11.00	0.07	3.11	8.56	4.88	0.00	0.00
26/8	42.40	11.00	0.09	3.61	4.49	2.47	1.14	0.02
5/9	42.22	11.00	0.10	4.12	0.00	0.00	4.12	0.07
15/9	42.22	11.00	0.11	4.64	0.00	0.00	4.64	0.08
25/9	42.39	11.00	0.12	4.90	0.00	0.00	4.90	0.08
5/10	42.71	11.00	0.12	4.93	0.00	0.00	4.93	0.08
15/10	43.14	11.00	0.12	4.98	0.00	0.00	4.98	0.08
25/10	43.65	11.00	0.12	5.04	0.00	0.00	5.04	0.08
4/11	44.20	11.00	0.11	4.90	0.00	0.00	4.90	0.08
14/11	44.76	11.00	0.10	4.60	0.00	0.00	4.60	0.08
Total	563.06			53.59	33.77	20.95	39.26	[0.05]

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Crop Water Requirements Report (Hadish Mebratum)

****

- Crop # 3 : Peppers
- Block # : [All blocks]
- Planting date : 17/7
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
17/7	46.57	60.00	0.36	16.77	35.78	26.12	0.00	0.00
27/7	45.52	60.00	0.36	16.39	37.13	27.29	0.00	0.00
6/8	44.65	60.00	0.36	16.07	33.05	24.69	0.00	0.00
16/8	43.97	60.00	0.40	17.46	23.46	17.98	0.00	0.00
26/8	43.49	60.00	0.46	20.20	9.18	7.27	12.93	0.21
5/9	43.20	60.00	0.53	22.99	0.00	0.00	22.99	0.38
15/9	43.11	60.00	0.60	25.85	0.00	0.00	25.85	0.43
25/9	43.20	60.00	0.63	27.21	0.00	0.00	27.21	0.45
5/10	43.44	60.00	0.63	27.37	0.00	0.00	27.37	0.45
15/10	43.81	60.00	0.63	27.60	0.00	0.00	27.60	0.46
25/10	44.27	60.00	0.63	27.89	0.00	0.00	27.89	0.46
4/11	44.81	60.00	0.61	27.12	0.00	0.00	27.12	0.45
14/11	45.36	60.00	0.56	25.41	0.00	0.00	25.41	0.42
Total	575.40			298.33	138.60	103.35	224.37	[0.29]

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Crop Water Requirements Report (Hagos Amare)

****

- Crop # 1 : Peppers
- Block # : [All blocks]
- Planting date : 17/7
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
17/7	45.85	89.00	0.53	24.48	36.94	29.28	0.00	0.00
27/7	44.82	89.00	0.53	23.94	47.94	35.56	0.00	0.00
6/8	43.97	89.00	0.53	23.48	54.62	38.54	0.00	0.00
16/8	43.30	89.00	0.59	25.50	50.47	34.41	0.00	0.00
26/8	42.82	89.00	0.69	29.51	26.53	18.02	11.49	0.19
5/9	42.53	89.00	0.79	33.57	0.24	0.24	33.33	0.55
15/9	42.43	89.00	0.89	37.74	0.00	0.00	37.74	0.62
25/9	42.49	89.00	0.93	39.71	0.00	0.00	39.71	0.66
5/10	42.70	89.00	0.93	39.90	0.00	0.00	39.90	0.66
15/10	43.04	89.00	0.93	40.22	0.00	0.00	40.22	0.66
25/10	43.46	89.00	0.93	40.62	0.00	0.00	40.62	0.67
4/11	43.95	89.00	0.90	39.45	0.00	0.00	39.45	0.65
14/11	44.45	89.00	0.83	36.94	0.00	0.00	36.94	0.61
Total	565.82			435.05	216.73	156.05	319.39	[0.41]

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Crop Water Requirements Report(Haily Berhe)

****

- Crop # 3 : Cucumber
- Block # : [All blocks]
- Planting date : 12/7
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
12/7	47.16	9.00	0.04	1.70	5.00	3.65	0.00	0.00
22/7	46.03	9.00	0.04	1.66	5.56	4.07	0.00	0.00
1/8	45.06	9.00	0.04	1.73	5.37	3.97	0.00	0.00
11/8	44.28	9.00	0.05	2.37	4.34	3.28	0.00	0.00
21/8	43.70	9.00	0.07	3.07	2.52	1.97	1.10	0.02
31/8	43.32	9.00	0.09	3.77	0.39	0.31	3.46	0.06
10/9	43.14	9.00	0.09	4.08	0.00	0.00	4.08	0.07
20/9	43.13	9.00	0.09	4.08	0.00	0.00	4.08	0.07
30/9	43.30	9.00	0.09	4.09	0.00	0.00	4.09	0.07
10/10	43.61	9.00	0.09	4.12	0.00	0.00	4.12	0.07
20/10	44.03	9.00	0.09	3.94	0.00	0.00	3.94	0.07
30/10	44.53	9.00	0.08	3.59	0.00	0.00	3.59	0.06
9/11	45.08	9.00	0.07	3.23	0.00	0.00	3.23	0.05
Total	576.38			41.42	23.18	17.25	31.68	[0.04]

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Crop Water Requirements Report(Lemlem Kahessay)

****

- Crop # 1 : CABBAGE (Crucifers)
- Block # : [All blocks]
- Planting date : 20/7
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
20/7	45.49	21.00	0.15	6.69	10.56	7.57	0.00	0.00
30/7	44.51	21.00	0.15	6.54	14.67	9.38	0.00	0.00
9/8	43.71	21.00	0.15	6.56	17.14	10.15	0.00	0.00
19/8	43.09	21.00	0.17	7.28	15.00	8.44	0.00	0.00
29/8	42.66	21.00	0.19	8.11	4.72	2.58	5.53	0.09
8/9	42.43	21.00	0.21	8.95	0.00	0.00	8.95	0.15
18/9	42.38	21.00	0.22	9.34	0.00	0.00	9.34	0.15
28/9	42.50	21.00	0.22	9.37	0.00	0.00	9.37	0.15
8/10	42.76	21.00	0.22	9.34	0.00	0.00	9.34	0.15
18/10	43.14	21.00	0.21	8.88	0.00	0.00	8.88	0.15
Total	432.68			81.07	62.09	38.12	51.42	[0.09]

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Crop Water Requirements Report(Lemlem Kahessay)

****

- Crop # 2 : TOMATO
- Block # : [All blocks]
- Planting date : 12/7
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
12/7	46.39	34.00	0.20	9.46	12.00	9.75	0.00	0.00
22/7	45.28	34.00	0.20	9.24	18.46	12.88	0.00	0.00
1/8	44.34	34.00	0.20	9.04	24.89	15.63	0.00	0.00
11/8	43.57	34.00	0.23	10.01	27.84	16.30	0.00	0.00
21/8	42.99	34.00	0.28	11.88	22.13	12.36	0.00	0.00
31/8	42.60	34.00	0.32	13.77	4.32	2.35	11.42	0.19
10/9	42.41	34.00	0.37	15.69	0.00	0.00	15.69	0.26
20/9	42.39	34.00	0.39	16.58	0.00	0.00	16.58	0.27
30/9	42.54	34.00	0.39	16.63	0.00	0.00	16.63	0.28
10/10	42.83	34.00	0.39	16.75	0.00	0.00	16.75	0.28
20/10	43.23	34.00	0.39	16.90	0.00	0.00	16.90	0.28
30/10	43.72	34.00	0.39	16.83	0.00	0.00	16.83	0.28
9/11	44.25	34.00	0.35	15.46	0.00	0.00	15.46	0.26
19/11	44.78	34.00	0.31	13.87	0.00	0.00	13.87	0.23
29/11	22.59	34.00	0.28	6.32	0.00	0.00	6.32	0.21
Total	633.90			198.43	109.65	69.28	146.44	[0.17]

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Crop Water Requirements Report (Amare Teare)

****

- Crop # 5 : Carrot
- Block # : [All blocks]
- Planting date : 15/7
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
15/7	45.32	18.00	0.13	5.71	7.31	5.65	0.06	0.00
25/7	44.32	18.00	0.13	5.58	10.86	7.31	0.00	0.00
4/8	43.50	18.00	0.14	5.98	13.94	8.55	0.00	0.00
14/8	42.88	18.00	0.16	6.80	14.47	8.33	0.00	0.00
24/8	42.46	18.00	0.18	7.62	9.38	5.18	2.44	0.04
3/9	42.24	18.00	0.19	7.98	0.49	0.27	7.72	0.13
13/9	42.20	18.00	0.19	7.98	0.00	0.00	7.98	0.13
23/9	42.34	18.00	0.19	8.00	0.00	0.00	8.00	0.13
3/10	42.63	18.00	0.18	7.78	0.00	0.00	7.78	0.13
13/10	21.46	18.00	0.17	3.72	0.00	0.00	3.72	0.12
Total	409.36			67.16	56.46	35.29	37.70	[0.07]

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Crop Water Requirements Report (Amare Teare)

- Crop # 6 : Potato
- Block # : [All blocks]
- Planting date : 10/7
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
10/7	45.88	23.00	0.11	5.28	7.37	6.21	0.00	0.00
20/7	44.80	23.00	0.11	5.15	11.56	8.29	0.00	0.00
30/7	43.89	23.00	0.12	5.37	16.06	10.27	0.00	0.00
9/8	43.17	23.00	0.17	7.22	18.77	11.12	0.00	0.00
19/8	42.64	23.00	0.22	9.26	16.43	9.25	0.01	0.00
29/8	42.32	23.00	0.26	10.98	5.17	2.83	8.16	0.13
8/9	42.20	23.00	0.26	11.16	0.00	0.00	11.16	0.18
18/9	42.25	23.00	0.26	11.18	0.00	0.00	11.18	0.18
28/9	42.47	23.00	0.26	11.23	0.00	0.00	11.23	0.19
8/10	42.82	23.00	0.26	11.33	0.00	0.00	11.33	0.19
18/10	43.28	23.00	0.25	10.72	0.00	0.00	10.72	0.18
28/10	43.81	23.00	0.22	9.50	0.00	0.00	9.50	0.16
7/11	44.37	23.00	0.19	8.26	0.00	0.00	8.26	0.14
Total	563.91			116.65	75.37	47.96	81.55	[0.10]

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Crop Water Requirements Report (Hadish Mebratume)

- Crop # 4 : Swiss Chared
- Block # : [All blocks]
- Planting date : 20/7
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
20/7	46.24	10.00	0.07	3.24	6.12	4.47	0.00	0.00
30/7	45.24	10.00	0.07	3.17	6.08	4.49	0.00	0.00
9/8	44.42	10.00	0.08	3.39	5.12	3.85	0.00	0.00
19/8	43.80	10.00	0.09	3.86	3.27	2.53	1.33	0.02
29/8	43.38	10.00	0.10	4.33	0.79	0.63	3.69	0.06
8/9	43.16	10.00	0.11	4.53	0.00	0.00	4.53	0.07
18/9	43.12	10.00	0.11	4.53	0.00	0.00	4.53	0.07
28/9	43.25	10.00	0.11	4.54	0.00	0.00	4.54	0.08
8/10	43.54	10.00	0.10	4.41	0.00	0.00	4.41	0.07
18/10	21.91	10.00	0.10	2.11	0.00	0.00	2.11	0.07
Total	418.07			38.11	21.38	15.97	25.15	[0.04]

Crop Water Requirements Report (Hagos Amare)

- Crop # 3 : Potato
- Block # : [All blocks]
- Planting date : 18/7
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
18/7	45.74	7.00	0.04	1.60	3.00	2.36	0.00	0.00
28/7	44.73	7.00	0.04	1.57	3.85	2.84	0.00	0.00
7/8	43.90	7.00	0.04	1.64	4.31	3.03	0.00	0.00
17/8	43.24	7.00	0.05	2.20	3.86	2.63	0.00	0.00
27/8	42.78	7.00	0.07	2.83	1.78	1.22	1.61	0.03
6/9	42.51	7.00	0.08	3.36	0.00	0.00	3.36	0.06
16/9	42.43	7.00	0.08	3.42	0.00	0.00	3.42	0.06
26/9	42.51	7.00	0.08	3.42	0.00	0.00	3.42	0.06
6/10	42.73	7.00	0.08	3.44	0.00	0.00	3.44	0.06
16/10	43.07	7.00	0.08	3.47	0.00	0.00	3.47	0.06
26/10	43.51	7.00	0.08	3.28	0.00	0.00	3.28	0.05
5/11	44.00	7.00	0.07	2.90	0.00	0.00	2.90	0.05
15/11	44.50	7.00	0.06	2.52	0.00	0.00	2.52	0.04
Total	565.65			35.64	16.80	12.07	27.42	[0.03]

Crop Water Requirements Report (Haily Berhe)

- Crop # 1 : TOMATO
- Planting date : 12/7
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
12/7	47.16	25.00	0.15	7.07	13.88	10.14	0.00	0.00
22/7	46.03	25.00	0.15	6.90	15.46	11.31	0.00	0.00
1/8	45.06	25.00	0.15	6.76	14.91	11.04	0.00	0.00
11/8	44.28	25.00	0.17	7.48	12.05	9.11	0.00	0.00
21/8	43.70	25.00	0.20	8.88	7.01	5.46	3.42	0.06
31/8	43.32	25.00	0.24	10.29	1.07	0.86	9.43	0.16
10/9	43.14	25.00	0.27	11.73	0.00	0.00	11.73	0.19
20/9	43.13	25.00	0.29	12.40	0.00	0.00	12.40	0.21
30/9	43.30	25.00	0.29	12.45	0.00	0.00	12.45	0.21
10/10	43.61	25.00	0.29	12.54	0.00	0.00	12.54	0.21
20/10	44.03	25.00	0.29	12.66	0.00	0.00	12.66	0.21
30/10	44.53	25.00	0.28	12.61	0.00	0.00	12.61	0.21
9/11	45.08	25.00	0.26	11.58	0.00	0.00	11.58	0.19
19/11	45.64	25.00	0.23	10.39	0.00	0.00	10.39	0.17
29/11	23.02	25.00	0.21	4.74	0.00	0.00	4.74	0.16
Total	645.03			148.49	64.38	47.91	113.95	[0.13]

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Crop Water Requirements Report (Lemlem Kahessay)

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- Crop # 5 : Carrot
- Block # : [All blocks]
- Planting date : 15/7
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm)	Total Rain	Effect. Rain	Irr. Req.	FWS (l/s/ha)
				(mm/period)				
15/7	46.05	12.00	0.08	3.87	4.87	3.76	0.10	0.00
25/7	44.98	12.00	0.08	3.78	7.24	4.87	0.00	0.00
4/8	44.09	12.00	0.09	4.04	9.30	5.70	0.00	0.00
14/8	43.37	12.00	0.11	4.58	9.64	5.55	0.00	0.00
24/8	42.85	12.00	0.12	5.13	6.25	3.46	1.67	0.03
3/9	42.52	12.00	0.13	5.36	0.33	0.18	5.18	0.09
13/9	42.38	12.00	0.13	5.34	0.00	0.00	5.34	0.09
23/9	42.42	12.00	0.13	5.34	0.00	0.00	5.34	0.09
3/10	42.61	12.00	0.12	5.18	0.00	0.00	5.18	0.09
13/10	21.42	12.00	0.12	2.48	0.00	0.00	2.48	0.08
Total	412.70			45.10	37.64	23.53	25.30	[0.04]

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Crop Water Requirements Report(Lemlem Kahessay)

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- Crop # 6 : White Cumin
- Block # : [All blocks]
- Planting date : 16/7
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm)	Total Rain	Effect. Rain	Irr. Req.	FWS (l/s/ha)
				(mm/period)				
16/7	45.93	5.00	0.02	0.92	2.12	1.61	0.00	0.00
26/7	44.88	5.00	0.02	0.90	3.12	2.07	0.00	0.00
5/8	44.01	5.00	0.02	0.95	3.93	2.39	0.00	0.00
15/8	43.31	5.00	0.03	1.35	3.96	2.27	0.00	0.00
25/8	42.81	5.00	0.04	1.80	2.34	1.29	0.51	0.01
4/9	42.50	5.00	0.05	2.24	0.05	0.03	2.21	0.04
14/9	42.38	5.00	0.06	2.44	0.00	0.00	2.44	0.04
24/9	42.43	5.00	0.06	2.44	0.00	0.00	2.44	0.04
4/10	42.64	5.00	0.06	2.45	0.00	0.00	2.45	0.04
14/10	42.98	5.00	0.06	2.47	0.00	0.00	2.47	0.04
24/10	43.42	5.00	0.06	2.45	0.00	0.00	2.45	0.04
3/11	43.92	5.00	0.05	2.16	0.00	0.00	2.16	0.04
13/11	44.46	5.00	0.04	1.84	0.00	0.00	1.84	0.03
23/11	44.99	5.00	0.03	1.51	0.00	0.00	1.51	0.02
Total	610.68			25.91	15.52	9.67	20.48	[0.02]

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Crop Water Requirements Report (Amare Teare)

****

- Crop # 1 : CABBAGE (Crucifers)
- Block # : [All blocks]
- Planting date : 20/7
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm)	Total Rain	Effect. Rain	Irr. Req.	FWS (l/s/ha)
				(mm/period)	(mm/period)	(mm/period)	(mm/period)	
20/7	44.80	11.00	0.08	3.45	5.53	3.96	0.00	0.00
30/7	43.89	11.00	0.08	3.38	7.68	4.91	0.00	0.00
9/8	43.17	11.00	0.08	3.39	8.98	5.32	0.00	0.00
19/8	42.64	11.00	0.09	3.78	7.86	4.42	0.00	0.00
29/8	42.32	11.00	0.10	4.21	2.47	1.35	2.86	0.05
8/9	42.20	11.00	0.11	4.67	0.00	0.00	4.67	0.08
18/9	42.25	11.00	0.12	4.88	0.00	0.00	4.88	0.08
28/9	42.47	11.00	0.12	4.91	0.00	0.00	4.91	0.08
8/10	42.82	11.00	0.11	4.90	0.00	0.00	4.90	0.08
18/10	43.28	11.00	0.11	4.67	0.00	0.00	4.67	0.08
Total	429.85			42.23	32.52	19.97	26.88	[0.04]

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Crop Water Requirements Report(Amare Tearre)

****

- Crop # 3 : Swiss chared
- Block # : [All blocks]
- Planting date : 20/7
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm)	Total Rain	Effect. Rain	Irr. Req.	FWS (l/s/ha)
				(mm/period)	(mm/period)	(mm/period)	(mm/period)	
20/7	44.80	17.00	0.12	5.33	8.55	6.12	0.00	0.00
30/7	43.89	17.00	0.12	5.22	11.87	7.59	0.00	0.00
9/8	43.17	17.00	0.13	5.61	13.88	8.22	0.00	0.00
19/8	42.64	17.00	0.15	6.39	12.14	6.83	0.00	0.00
29/8	42.32	17.00	0.17	7.18	3.82	2.09	5.09	0.08
8/9	42.20	17.00	0.18	7.53	0.00	0.00	7.53	0.12
18/9	42.25	17.00	0.18	7.54	0.00	0.00	7.54	0.12
28/9	42.47	17.00	0.18	7.58	0.00	0.00	7.58	0.13
8/10	42.82	17.00	0.17	7.38	0.00	0.00	7.38	0.12
18/10	21.58	17.00	0.16	3.53	0.00	0.00	3.53	0.12
Total	408.14			63.29	50.26	30.86	38.65	[0.07]

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Crop Water Requirements Report (Hadish Mebratum)

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- Crop # 2 : TOMATO
- Block # : [All blocks]
- Planting date : 12/7
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
12/7	47.16	10.00	0.06	2.83	5.55	4.06	0.00	0.00
22/7	46.03	10.00	0.06	2.76	6.18	4.52	0.00	0.00
1/8	45.06	10.00	0.06	2.70	5.97	4.41	0.00	0.00
11/8	44.28	10.00	0.07	2.99	4.82	3.64	0.00	0.00
21/8	43.70	10.00	0.08	3.55	2.80	2.18	1.37	0.02
31/8	43.32	10.00	0.10	4.12	0.43	0.34	3.77	0.06
10/9	43.14	10.00	0.11	4.69	0.00	0.00	4.69	0.08
20/9	43.13	10.00	0.11	4.96	0.00	0.00	4.96	0.08
30/9	43.30	10.00	0.11	4.98	0.00	0.00	4.98	0.08
10/10	43.61	10.00	0.11	5.01	0.00	0.00	5.01	0.08
20/10	44.03	10.00	0.11	5.06	0.00	0.00	5.06	0.08
30/10	44.53	10.00	0.11	5.04	0.00	0.00	5.04	0.08
9/11	45.08	10.00	0.10	4.63	0.00	0.00	4.63	0.08
19/11	45.64	10.00	0.09	4.16	0.00	0.00	4.16	0.07
29/11	23.02	10.00	0.08	1.90	0.00	0.00	1.90	0.06
Total	645.03			59.39	25.75	19.16	45.58	[0.05]

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Crop Water Requirements Report(Lemlem Kahessay)

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- Crop # 4 : Lettuce
- Block # : [All blocks]
- Planting date : 20/7
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
20/7	45.49	16.00	0.11	5.10	8.04	5.76	0.00	0.00
30/7	44.51	16.00	0.11	4.99	11.17	7.14	0.00	0.00
9/8	43.71	16.00	0.12	5.34	13.06	7.74	0.00	0.00
19/8	43.09	16.00	0.14	6.07	11.43	6.43	0.00	0.00
29/8	42.66	16.00	0.16	6.81	3.60	1.97	4.84	0.08
8/9	42.43	16.00	0.17	7.13	0.00	0.00	7.13	0.12
18/9	42.38	16.00	0.17	7.12	0.00	0.00	7.12	0.12
28/9	42.50	16.00	0.17	7.14	0.00	0.00	7.14	0.12
8/10	42.76	16.00	0.16	6.93	0.00	0.00	6.93	0.11
18/10	21.52	16.00	0.15	3.32	0.00	0.00	3.32	0.11
Total	411.05			59.94	47.31	29.04	36.48	[0.06]

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Crop Water Requirements Report(Amare Teare)

****

- Crop # 4 : Lettuce
- Block # : [All blocks]
- Planting date : 20/7
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
20/7	44.80	20.00	0.14	6.27	10.05	7.20	0.00	0.00
30/7	43.89	20.00	0.14	6.14	13.97	8.93	0.00	0.00
9/8	43.17	20.00	0.15	6.60	16.33	9.67	0.00	0.00
19/8	42.64	20.00	0.18	7.51	14.28	8.04	0.00	0.00
29/8	42.32	20.00	0.20	8.44	4.50	2.46	5.99	0.10
8/9	42.20	20.00	0.21	8.86	0.00	0.00	8.86	0.15
18/9	42.25	20.00	0.21	8.87	0.00	0.00	8.87	0.15
28/9	42.47	20.00	0.21	8.92	0.00	0.00	8.92	0.15
8/10	42.82	20.00	0.20	8.68	0.00	0.00	8.68	0.14
18/10	21.58	20.00	0.19	4.16	0.00	0.00	4.16	0.14
Total	408.14			74.46	59.13	36.30	45.48	[0.08]

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Crop Water Requirements Report(Hadish Mebratume)

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- Crop # 1 : CABBAGE (Crucifers)
- Block # : [All blocks]
- Planting date : 20/7
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
20/7	46.24	2.00	0.01	0.65	1.22	0.89	0.00	0.00
30/7	45.24	2.00	0.01	0.63	1.22	0.90	0.00	0.00
9/8	44.42	2.00	0.01	0.64	1.02	0.77	0.00	0.00
19/8	43.80	2.00	0.02	0.71	0.65	0.51	0.20	0.00
29/8	43.38	2.00	0.02	0.79	0.16	0.13	0.66	0.01
8/9	43.16	2.00	0.02	0.87	0.00	0.00	0.87	0.01
18/9	43.12	2.00	0.02	0.91	0.00	0.00	0.91	0.01
28/9	43.25	2.00	0.02	0.91	0.00	0.00	0.91	0.02
8/10	43.54	2.00	0.02	0.91	0.00	0.00	0.91	0.01
18/10	43.94	2.00	0.02	0.86	0.00	0.00	0.86	0.01
Total	440.09			7.85	4.28	3.19	5.31	[0.01]

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

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Crop Water Requirements Report(Hagos Amare)

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- Crop # 2 : Onion
- Block # : [All blocks]
- Planting date : 13/7
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm)	Total Rain	Effect. Rain	Irr. Req.	FWS (l/s/ha)
				(mm/period)				
13/7	46.30	4.00	0.03	1.30	1.45	1.19	0.11	0.00
23/7	45.21	4.00	0.03	1.27	1.97	1.50	0.00	0.00
2/8	44.29	4.00	0.03	1.35	2.37	1.71	0.00	0.00
12/8	43.55	4.00	0.04	1.53	2.42	1.67	0.00	0.00
22/8	42.99	4.00	0.04	1.72	1.76	1.19	0.53	0.01
1/9	42.63	4.00	0.04	1.79	0.28	0.20	1.59	0.03
11/9	42.45	4.00	0.04	1.78	0.00	0.00	1.78	0.03
21/9	42.45	4.00	0.04	1.78	0.00	0.00	1.78	0.03
1/10	42.60	4.00	0.04	1.73	0.00	0.00	1.73	0.03
11/10	21.40	4.00	0.04	0.82	0.00	0.00	0.82	0.03
Total	413.87			15.07	10.26	7.45	8.34	[0.01]

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Crop Water Requirements Report(Haily Berhe)

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- Crop # 2 : Peppers
- Block # : [All blocks]
- Planting date : 17/7
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm)	Total Rain	Effect. Rain	Irr. Req.	FWS (l/s/ha)
				(mm/period)				
17/7	46.57	66.00	0.40	18.44	39.36	28.73	0.00	0.00
27/7	45.52	66.00	0.40	18.03	40.84	30.02	0.00	0.00
6/8	44.65	66.00	0.40	17.68	36.36	27.16	0.00	0.00
16/8	43.97	66.00	0.44	19.20	25.81	19.78	0.00	0.00
26/8	43.49	66.00	0.51	22.22	10.10	8.00	14.22	0.24
5/9	43.20	66.00	0.59	25.29	0.00	0.00	25.29	0.42
15/9	43.11	66.00	0.66	28.44	0.00	0.00	28.44	0.47
25/9	43.20	66.00	0.69	29.94	0.00	0.00	29.94	0.49
5/10	43.44	66.00	0.69	30.10	0.00	0.00	30.10	0.50
15/10	43.81	66.00	0.69	30.36	0.00	0.00	30.36	0.50
25/10	44.27	66.00	0.69	30.68	0.00	0.00	30.68	0.51
4/11	44.81	66.00	0.67	29.83	0.00	0.00	29.83	0.49
14/11	45.36	66.00	0.62	27.95	0.00	0.00	27.95	0.46
Total	575.40			328.16	152.46	113.68	246.81	[0.31]

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

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Crop Water Requirements Report (Lemlem Kahessay)

- Crop # 7 : Black Camin
- Block # : [All blocks]
- Planting date : 16/7
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
16/7	45.93	6.00	0.02	1.10	2.55	1.94	0.00	0.00
26/7	44.88	6.00	0.02	1.08	3.74	2.49	0.00	0.00
5/8	44.01	6.00	0.03	1.14	4.72	2.87	0.00	0.00
15/8	43.31	6.00	0.04	1.62	4.76	2.73	0.00	0.00
25/8	42.81	6.00	0.05	2.16	2.80	1.55	0.61	0.01
4/9	42.50	6.00	0.06	2.69	0.06	0.03	2.66	0.04
14/9	42.38	6.00	0.07	2.92	0.00	0.00	2.92	0.05
24/9	42.43	6.00	0.07	2.93	0.00	0.00	2.93	0.05
4/10	42.64	6.00	0.07	2.94	0.00	0.00	2.94	0.05
14/10	42.98	6.00	0.07	2.97	0.00	0.00	2.97	0.05
24/10	43.42	6.00	0.07	2.93	0.00	0.00	2.93	0.05
3/11	43.92	6.00	0.06	2.60	0.00	0.00	2.60	0.04
13/11	44.46	6.00	0.05	2.21	0.00	0.00	2.21	0.04
23/11	44.99	6.00	0.04	1.81	0.00	0.00	1.81	0.03
Total	610.68			31.09	18.62	11.60	24.57	[0.03]

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Crop Water Requirements Report(Seyum Wahid)

- Crop # 1 : CABBAGE (Crucifers)
- Block # : [All blocks]
- Planting date : 20/7
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
20/7	45.52	4.00	0.03	1.27	1.82	1.41	0.00	0.00
30/7	44.55	4.00	0.03	1.25	2.28	1.66	0.00	0.00
9/8	43.75	4.00	0.03	1.25	2.47	1.72	0.00	0.00
19/8	43.14	4.00	0.03	1.39	2.06	1.40	0.00	0.00
29/8	42.72	4.00	0.04	1.55	0.68	0.47	1.08	0.02
8/9	42.48	4.00	0.04	1.71	0.00	0.00	1.71	0.03
18/9	42.43	4.00	0.04	1.78	0.00	0.00	1.78	0.03
28/9	42.54	4.00	0.04	1.79	0.00	0.00	1.79	0.03
8/10	42.79	4.00	0.04	1.78	0.00	0.00	1.78	0.03
18/10	43.16	4.00	0.04	1.69	0.00	0.00	1.69	0.03
Total	433.07			15.46	9.30	6.65	9.83	[0.02]

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Crop Water Requirements Report(Seyum Wahid)

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- Crop # 2 : Sweet Peppers
- Planting date : 17/7
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
17/7	45.85	18.00	0.11	4.95	7.47	5.92	0.00	0.00
27/7	44.82	18.00	0.11	4.84	9.70	7.19	0.00	0.00
6/8	43.97	18.00	0.11	4.75	11.05	7.79	0.00	0.00
16/8	43.30	18.00	0.12	5.16	10.21	6.96	0.00	0.00
26/8	42.82	18.00	0.14	5.97	5.36	3.64	2.32	0.04
5/9	42.53	18.00	0.16	6.79	0.05	0.05	6.74	0.11
15/9	42.43	18.00	0.18	7.63	0.00	0.00	7.63	0.13
25/9	42.49	18.00	0.19	8.03	0.00	0.00	8.03	0.13
5/10	42.70	18.00	0.19	8.07	0.00	0.00	8.07	0.13
15/10	43.04	18.00	0.19	8.13	0.00	0.00	8.13	0.13
25/10	43.46	18.00	0.19	8.21	0.00	0.00	8.21	0.14
4/11	43.95	18.00	0.18	7.98	0.00	0.00	7.98	0.13
14/11	44.45	18.00	0.17	7.47	0.00	0.00	7.47	0.12
Total	565.82			87.99	43.83	31.56	64.60	[0.08]

****

Crop Water Requirements Report (Seyum Wahid)

****

- Crop # 4 : Sweet Potato
- Planting date : 18/7
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
18/7	45.74	9.00	0.03	1.44	3.85	3.03	0.00	0.00
28/7	44.73	9.00	0.03	1.41	4.94	3.65	0.00	0.00
7/8	43.90	9.00	0.03	1.53	5.54	3.90	0.00	0.00
17/8	43.24	9.00	0.05	2.35	4.97	3.38	0.00	0.00
27/8	42.78	9.00	0.08	3.26	2.29	1.56	1.70	0.03
6/9	42.51	9.00	0.10	4.17	0.00	0.00	4.17	0.07
16/9	42.43	9.00	0.11	4.58	0.00	0.00	4.58	0.08
26/9	42.51	9.00	0.11	4.59	0.00	0.00	4.59	0.08
6/10	42.73	9.00	0.11	4.61	0.00	0.00	4.61	0.08
16/10	43.07	9.00	0.11	4.65	0.00	0.00	4.65	0.08
26/10	43.51	9.00	0.11	4.70	0.00	0.00	4.70	0.08
5/11	44.00	9.00	0.10	4.53	0.00	0.00	4.53	0.07
15/11	44.50	9.00	0.09	4.19	0.00	0.00	4.19	0.07
25/11	44.99	9.00	0.09	3.83	0.00	0.00	3.83	0.06
5/12	45.42	9.00	0.08	3.45	0.00	0.00	3.45	0.06
15/12	45.76	9.00	0.07	3.07	0.00	0.00	3.07	0.05
Total	701.83			56.37	21.60	15.52	48.08	[0.05]

7/29/2005 CropWat 4 Windows Ver 4.3

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Crop Water Requirements Report (Seyum Wahid)

****

- Crop # 7 : Black Cumin
- Block # : [All blocks]
- Planting date : 16/7
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
16/7	45.96	23.00	0.09	4.23	9.25	7.38	0.00	0.00
26/7	44.92	23.00	0.09	4.13	12.13	9.05	0.00	0.00
5/8	44.05	23.00	0.10	4.38	14.04	9.95	0.00	0.00
15/8	43.36	23.00	0.14	6.23	13.34	9.12	0.00	0.00
25/8	42.86	23.00	0.19	8.27	7.78	5.27	3.00	0.05
4/9	42.55	23.00	0.24	10.31	0.26	0.21	10.10	0.17
14/9	42.43	23.00	0.26	11.22	0.00	0.00	11.22	0.19
24/9	42.48	23.00	0.26	11.24	0.00	0.00	11.24	0.19
4/10	42.67	23.00	0.26	11.29	0.00	0.00	11.29	0.19
14/10	43.00	23.00	0.26	11.37	0.00	0.00	11.37	0.19
24/10	43.42	23.00	0.26	11.25	0.00	0.00	11.25	0.19
3/11	43.90	23.00	0.23	9.94	0.00	0.00	9.94	0.16
13/11	44.40	23.00	0.19	8.45	0.00	0.00	8.45	0.14
23/11	44.90	23.00	0.15	6.92	0.00	0.00	6.92	0.11
Total	610.89			119.24	56.80	40.98	94.79	[0.11]

7/29/2005 CropWat 4 Windows Ver 4.3

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Crop Water Requirements Report (Seyum Wahid)

****

- Crop # 3 : Onion
- Block # : [All blocks]
- Planting date : 13/7
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
13/7	46.30	1.00	0.01	0.32	0.36	0.30	0.03	0.00
23/7	45.21	1.00	0.01	0.32	0.49	0.37	0.00	0.00
2/8	44.29	1.00	0.01	0.34	0.59	0.43	0.00	0.00
12/8	43.55	1.00	0.01	0.38	0.61	0.42	0.00	0.00
22/8	42.99	1.00	0.01	0.43	0.44	0.30	0.13	0.00
1/9	42.63	1.00	0.01	0.45	0.07	0.05	0.40	0.01
11/9	42.45	1.00	0.01	0.45	0.00	0.00	0.45	0.01
21/9	42.45	1.00	0.01	0.45	0.00	0.00	0.45	0.01
1/10	42.60	1.00	0.01	0.43	0.00	0.00	0.43	0.01
11/10	21.40	1.00	0.01	0.21	0.00	0.00	0.21	0.01
Total	413.87			3.77	2.57	1.86	2.09	[0.00]

Crop Water Requirements Report (Seyum Wahid)

- Crop # 5 : Potato
- Block # : [All blocks]
- Planting date : 10/7
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm)	Total Rain	Effect. Rain	Irr. Req.	FWS (l/s/ha)
				(mm/period)				
10/7	46.66	7.00	0.04	1.63	2.28	1.91	0.00	0.00
20/7	45.52	7.00	0.04	1.59	3.18	2.46	0.00	0.00
30/7	44.55	7.00	0.04	1.66	3.98	2.91	0.00	0.00
9/8	43.75	7.00	0.05	2.23	4.32	3.01	0.00	0.00
19/8	43.14	7.00	0.07	2.85	3.61	2.44	0.41	0.01
29/8	42.72	7.00	0.08	3.37	1.19	0.82	2.55	0.04
8/9	42.48	7.00	0.08	3.42	0.00	0.00	3.42	0.06
18/9	42.43	7.00	0.08	3.42	0.00	0.00	3.42	0.06
28/9	42.54	7.00	0.08	3.42	0.00	0.00	3.42	0.06
8/10	42.79	7.00	0.08	3.44	0.00	0.00	3.44	0.06
18/10	43.16	7.00	0.08	3.25	0.00	0.00	3.25	0.05
28/10	43.60	7.00	0.07	2.88	0.00	0.00	2.88	0.05
7/11	44.10	7.00	0.06	2.50	0.00	0.00	2.50	0.04
Total	567.43			35.67	18.56	13.55	25.30	[0.03]

Crop Water Requirements Report (Seyum Wahid)

- Crop # 6 : White Cumin
- Block # : [All blocks]
- Planting date : 16/7
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 70%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm)	Total Rain	Effect. Rain	Irr. Req.	FWS (l/s/ha)
				(mm/period)				
16/7	45.96	21.00	0.08	3.86	8.44	6.74	0.00	0.00
26/7	44.92	21.00	0.08	3.77	11.08	8.27	0.00	0.00
5/8	44.05	21.00	0.09	4.00	12.81	9.08	0.00	0.00
15/8	43.36	21.00	0.13	5.69	12.18	8.32	0.00	0.00
25/8	42.86	21.00	0.18	7.55	7.11	4.81	2.74	0.05
4/9	42.55	21.00	0.22	9.41	0.24	0.19	9.22	0.15
14/9	42.43	21.00	0.24	10.25	0.00	0.00	10.25	0.17
24/9	42.48	21.00	0.24	10.26	0.00	0.00	10.26	0.17
4/10	42.67	21.00	0.24	10.31	0.00	0.00	10.31	0.17
14/10	43.00	21.00	0.24	10.38	0.00	0.00	10.38	0.17
24/10	43.42	21.00	0.24	10.27	0.00	0.00	10.27	0.17
3/11	43.90	21.00	0.21	9.08	0.00	0.00	9.08	0.15
13/11	44.40	21.00	0.17	7.72	0.00	0.00	7.72	0.13
23/11	44.90	21.00	0.14	6.32	0.00	0.00	6.32	0.10
Total	610.89			108.87	51.86	37.42	86.55	[0.10]

APPENDIX I. Monthly mean Evapotranspiration (Estimated by cropWat 4 Windows software)

3/11/2005 CropWat 4 Windows Ver 4.3

Climate and ETo (grass) Data for Kilte Awulaelo woreda

Data Source: [Keyboard]

Country : Ethiopia Station : Mekelle and Wukro
Altitude: 2070 meter(s) above M.S.L.
Latitude: 14.94 km (North) Longitude: 5.54 km (East)

Month	MaxTemp (deg.C)	MiniTemp (deg.C)	Humidity (%)	Wind Spd. (Km/d)	SunShine (Hours)	Solar Rad. (MJ/m2/d)	ETo (mm/d)
January	28.3	7.9	61.0	130.0	10.6	21.3	4.12
February	28.3	9.9	58.0	138.0	10.6	23.1	4.62
March	29.1	14.3	57.0	147.0	10.5	24.8	5.24
April	29.7	14.9	54.0	156.0	10.4	25.6	5.64
May	30.2	15.8	48.0	173.0	11.1	26.5	6.07
June	30.6	15.0	51.0	164.0	10.1	24.6	5.74
July	27.4	15.6	78.0	156.0	7.6	20.9	4.38
August	26.5	15.8	82.0	156.0	7.0	20.2	4.09
September	27.5	12.9	65.0	147.0	10.1	24.4	4.93
October	26.9	12.2	55.0	181.0	10.5	23.5	4.93
November	26.7	9.6	58.0	121.0	10.2	21.1	3.96
December	26.1	7.8	62.0	112.0	10.7	20.8	3.63
Average	28.1	12.6	60.8	148.4	9.9	23.1	4.78

Climate and ETo (grass) Data for Haikemesehal area

Data Source: C:\CROPWATW\CLIMATE\HAIKMES.PEM

Country : ETHIOPIA Station : MEKELLE
Altitude: 2070 meter(s) above M.S.L.
Latitude: 13.30 Deg. (North) Longitude: 39.29 Deg. (East)

Month	MaxTemp (deg.C)	MiniTemp (deg.C)	Humidity (%)	Wind Spd. (Km/d)	SunShine (Hours)	Solar Rad. (MJ/m2/d)	ETo (mm/d)
January	23.5	9.0	61.0	292.9	9.5	20.3	4.46
February	24.7	10.1	52.0	335.2	9.5	21.9	5.42
March	25.6	11.6	57.0	337.0	9.0	22.7	5.61
April	26.2	13.1	53.0	334.4	9.2	23.7	6.02
May	27.2	13.8	45.0	267.0	9.8	24.4	6.16
June	27.6	13.6	52.0	267.0	9.8	24.0	5.94
July	23.6	12.8	77.0	167.6	5.3	17.4	3.59
August	23.1	12.6	82.0	140.8	5.4	17.7	3.42
September	24.8	11.7	61.0	153.8	8.3	21.8	4.45
October	24.0	11.3	56.0	263.5	9.4	22.2	4.91
November	23.0	10.1	56.0	304.1	9.8	21.0	4.67
December	22.8	9.0	58.0	314.5	9.8	20.1	4.46
Average	24.7	11.6	59.2	264.8	8.7	21.4	4.93

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Climate and ETo (grass) Data for Hintalo Wajerate woreda

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Data Source: C:\CROPWATW\CLIMATE\HINTALO.PEM

Country : ETHIOPIA Station : MEKELLE
Altitude: 2070 meter(s) above M.S.L.
Latitude: 13.30 Deg. (North) Longitude: 39.29 Deg. (East)

Month	MaxTemp (deg.C)	MiniTemp (deg.C)	Humidity (%)	Wind Spd. (Km/d)	SunShine (Hours)	Solar Rad. (MJ/m2/d)	ETo (mm/d)
January	23.1	8.7	61.0	292.9	9.5	20.3	4.41
February	24.7	10.1	52.0	335.2	9.5	21.9	5.42
March	25.6	11.6	57.0	337.0	9.0	22.7	5.61
April	26.2	13.1	53.0	334.4	9.2	23.7	6.02
May	27.2	13.8	45.0	267.0	9.8	24.4	6.16
June	27.6	13.6	52.0	267.0	9.8	24.0	5.94
July	23.6	12.8	77.0	167.6	5.3	17.4	3.59
August	23.1	12.6	82.0	140.8	5.4	17.7	3.42
September	24.8	11.7	61.0	153.8	8.3	21.8	4.45
October	24.0	11.3	56.0	263.5	9.4	22.2	4.91
November	23.0	10.1	56.0	304.1	9.8	21.0	4.67
December	22.8	9.0	58.0	314.5	9.8	20.1	4.46
Average	24.6	11.5	59.2	264.8	8.7	21.4	4.92

Pen-Mon equation was used in ETo calculations with the following values for Angstrom's Coefficients:

a = 0.25 b = 0.5

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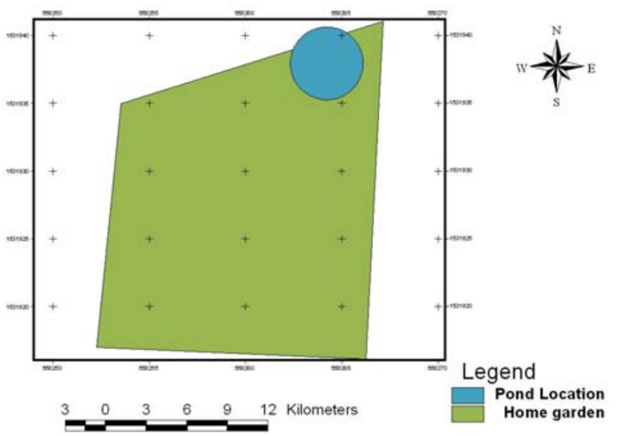
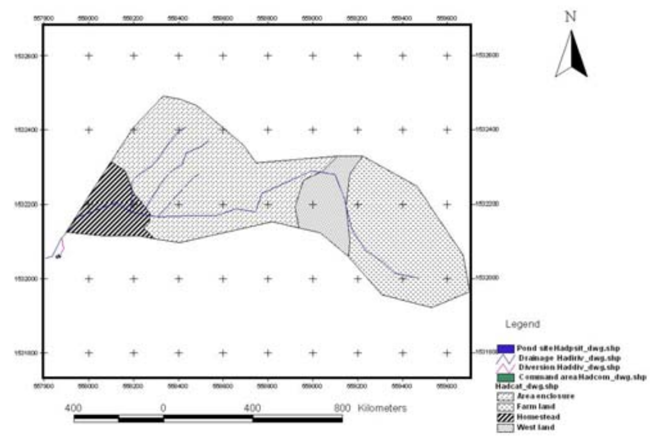
C:\CROPWATW\REPORTS\HINTALO.TXT

APPENDiX J . Location of catchment area, ponds and homegarden

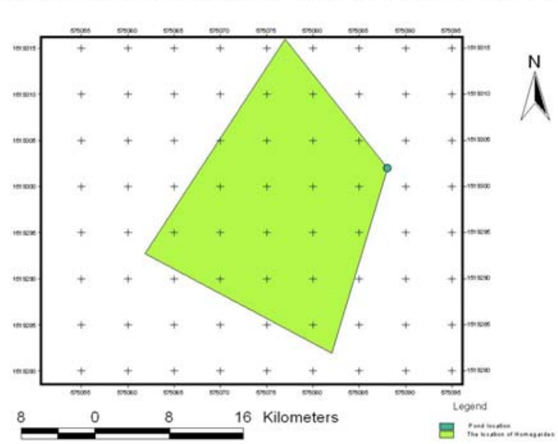
Map of the Homegarden and pond Kilteawlalo, Abrha atsbeha, Haily Berhe



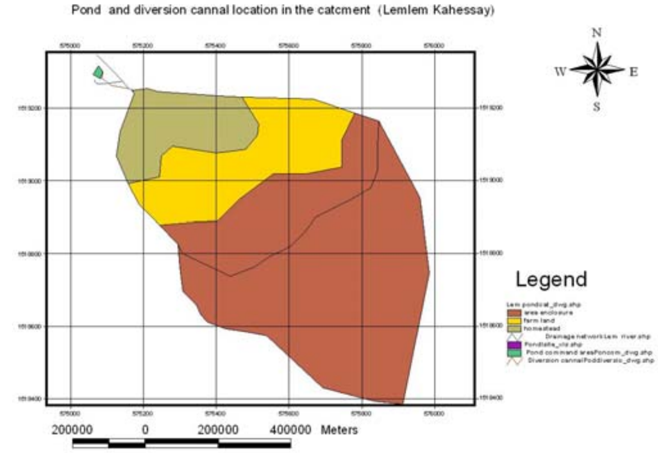
Pond catchement , diversion and location map for Hadish mebratu, Kilite awelalo, Abrha atsbeha



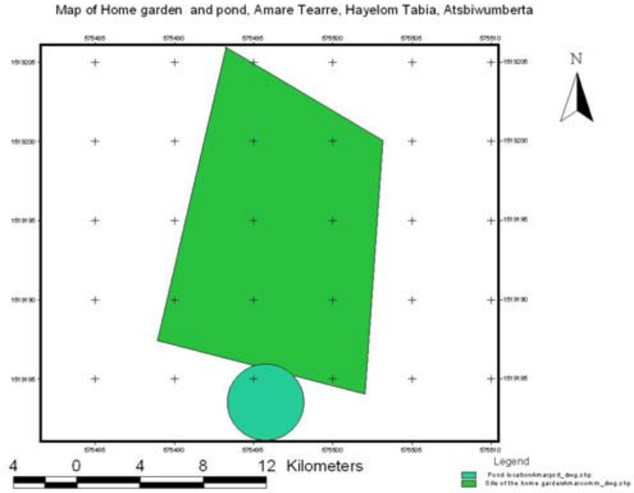
Map of homegarden and pondlocation, Lemlem Kahessay, Atsbiwumberta, Hayelom Tabia



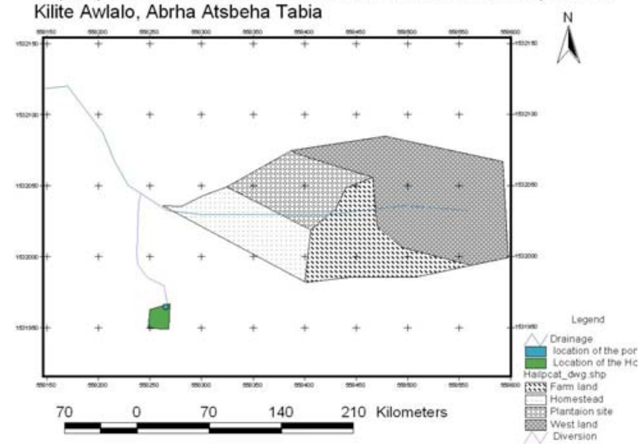
Pond and diversion cannal location in the catcment (Lemlem Kahessay)

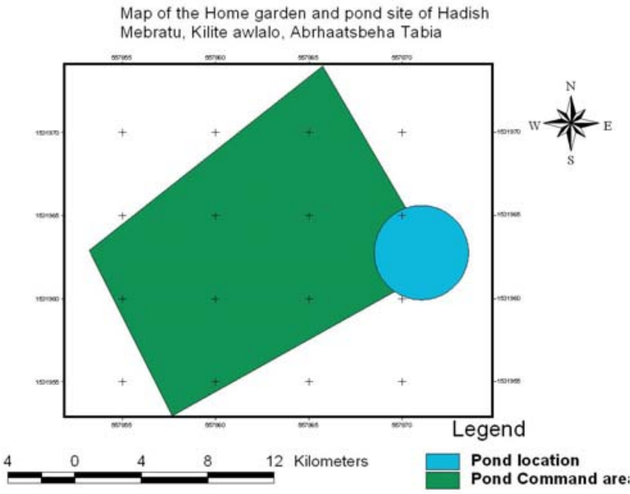


Map of Home garden and pond, Amare Tearre, Hayelom Tabia, Atsbiwumberta

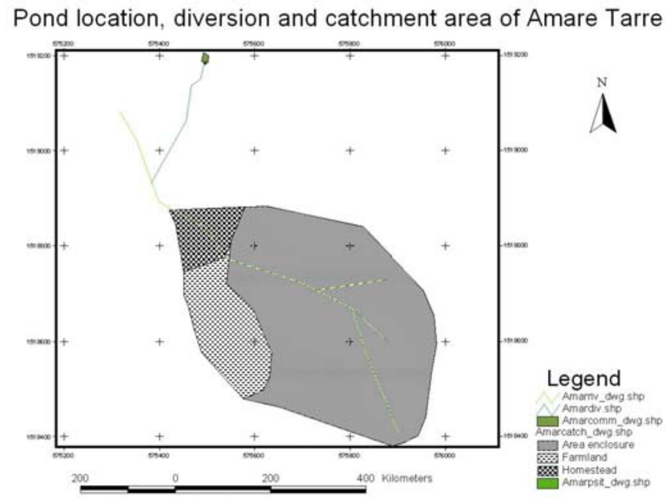


Map of pond catchment,diversion and command area of Haily Berhe, Kilite Awlalo, Abrha Atsbeha Tabia

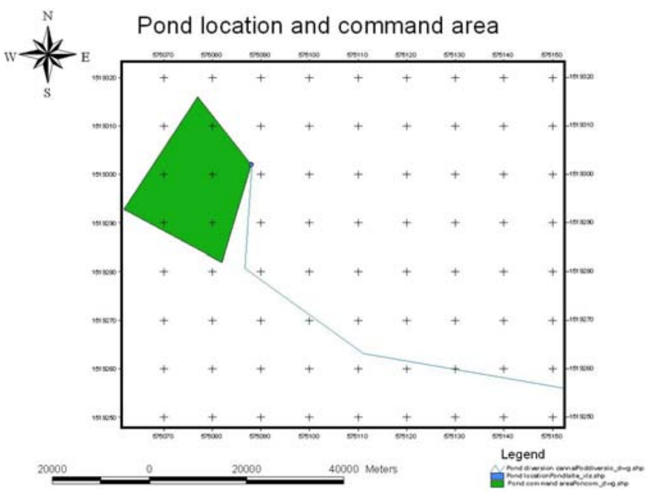




Map of the Home garden and pond site of Hadish
Mebratu, Kilite awlalo, Abrhaatsbeha Tabia
N
W
E
S
Legend
4 0 4 8 12 Kilometers
Pond location
Pond Command are



Pond location, diversion and catchment area of Amare Tarre
N
Legend
Amarriv_dwg.shp
Amardiv.shp
Amarcomm_dwg.shp
Amarcatch_dwg.shp
Area enclosure
Farmland
Homestead
Amarpsit_dwg.shp
200 0 200 400 Kilometers



N
W
E
S
Pond location and command area
Legend
20000 0 20000 40000 Meters

APPENDIX K. Pictures Gallery which shows the various pond types, irrigable area and other

Cement lined Trapezoidal pond

Well fenced plastic lined Trapezoidal pond

Plastic lined Trapezoidal pond

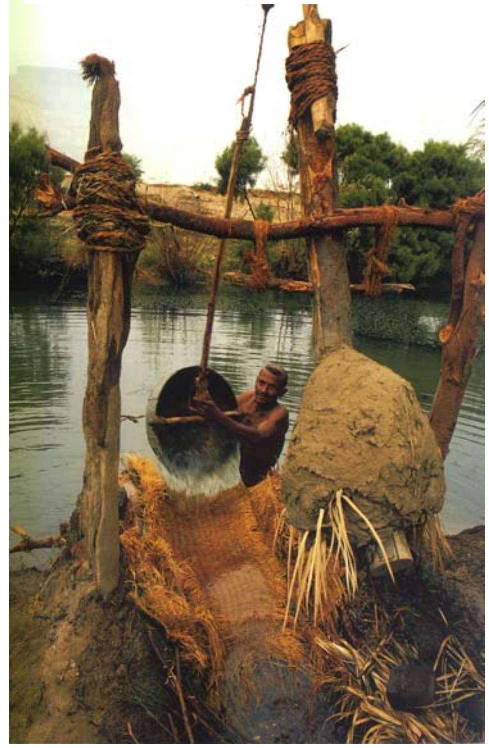
Clay lined Trapezoidal pond

Plastic lined pond

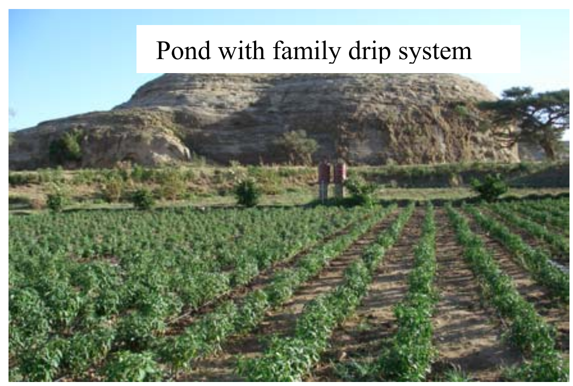
Pond with effective garden


Cylindrical pond lined

Traditional water withdrawal systems



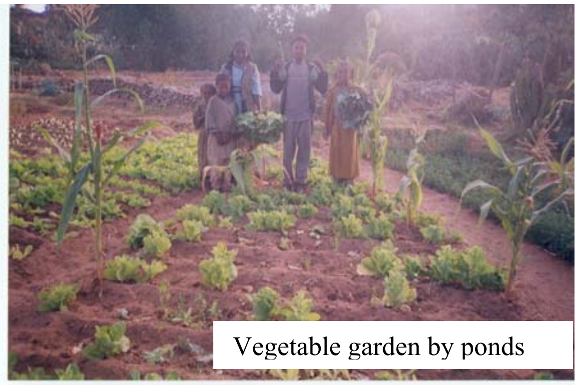

Damaged plastic lining


Pond with family drip system

An alga "Segue" used for minimizing evaporation loss

Homegarden in Haykemeshal

Profile pits in the garden



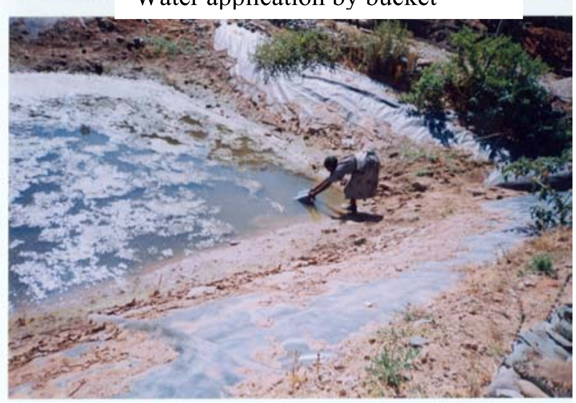
Vegetable garden by ponds

Tridle pump application for pond

Measurement of pond water level

Homegarden in maynebri

Water application by bucket



Homegarden in Abrha atsbha

Homegarden in Haykemeshal

Homegarden with drip system

Homegarden with drip system

Homegarden in Haykemeshal