



Research Paper

Towards Optimal Irrigation Water Abstraction in Haramaya Dry Lake Basin

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ABSTRACT

The water resources, surface and ground water of the dry Haramaya Lake Basin was used for agriculture and water supply purposes by different communities in a non-sustainable manner. Since the disappearance of the lake, agricultural (irrigated) area has expanded to the dry lake and farmers started pump water out of the basin ground water irregularly. This increase in irrigated land coupled with the inefficient and over irrigation has placed further pressure on the depleting water resource of the basin. Hence, this study was carried out to review and evaluate the existing irrigation water management practices and develop alternative intervention for optimum irrigation water withdrawal from the dry Haramaya Lake basin. Field measurements, interview and focal group discussion were made to collect primary and secondary data related to soil, crop, metrological and irrigation parameters. The irrigation water withdrawal under the existing condition was estimated considering the pumping rate, irrigation duration and interval and area irrigated. In addition, CROPWAT software was used to determine the water requirement of crops for the ET based irrigation system. For all crops, the applied irrigation water under the traditional irrigation was well above the recommended rate. A reduction in applied irrigation depth of 60% (minimum) and 92% (maximum) was obtained by shifting from the traditional irrigation system into the ET based irrigation system. The water productivity increased by 796% for cabbage and 75% for tomato in the ET based irrigation system as compared to the traditional irrigation system. Similarly, with the ET based irrigation system, the average water withdrawal per hectare of land decreased by 73% (from 15932 to 4282 m³/ha). This study, therefore, urges for immediate intervention in replacing the existing traditional system to the ET based irrigation system.

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INTRODUCTION

Agriculture accounts for more than two-third of human water withdrawals (Gleick, 2002). The reason is that approximately, 40% of the world's food comes from the 17% of the world's cropland that is irrigated and that dependence on irrigated land is expected to increase in the future with majority of it being in developing countries (Playan and Mateos, 2006; Shiklomanov, 2000). Moreover, doubling of food production over the next 25 years would

result in roughly a doubling of water utilization in agriculture causing increased withdrawals of water in rain-fed and irrigated agriculture which may have negative implications for basin wide water availability to sustain human livelihood and ecosystem services (Rockström et al., 2003). The impact would be more pronounced in developing countries which experience low crop yield levels and large on-farm water losses (Kijne et al., 2003).

Thus, as irrigation is becoming large consumer of water, developments in irrigation have profound impacts on basin-wide water use and availability (Molden, 1997a). In Ethiopia, like the other developed and developing nations, groundwater is of paramount importance to supplement the available surface water resources in providing drinking water and economic development. Likewise, Lake Haramaya has been used for different purposes by different communities until it completely dried in 2004/2005 (Edo, 2009). It was utilized as a source of groundwater supply for the three major towns: Harar, Haramaya, Awoday and Haramaya University main campus (Tadesse et al., 2010). As the lake vanished, agricultural area expanded to the dry lake and irrigated land area increased thereby creating extra pressure on the depleting water resource of the basin. Obstruction of water has now shifted to the remains of an underground pool beneath the Lake dry basin. Almost all the farmers are irregularly pumping water out of the lake ground water for different purposes. Subjected to the inefficient and over irrigation practice lot and lots of water is being extracted from the dry lake basin. More than 180 hand dug wells constructed by the farmers are intensively pumping groundwater from the dry lake basin for domestic, irrigation and livestock purposes (Tadesse and Abdulaziz, 2009). It is necessary some measures to develop some new water management strategy and regulate the water withdrawals are taken.

Excessive evapo-transpiration and minimized precipitation as a result of climate change is also directly affecting the amount of recharge into the dry lake basin (Alemayehu et al., 2007). Moreover, Lemma (2003) reported that changing climatic conditions, adverse effects of deforestation, erosion and transport of top soil in the lake as indirect effects aggravates the continuous shrinkage and drying of the lake. The issue of unsustainable use arises when the mismatch between demand and supply leads to over-exploitation of a single resource as it is in the study area, the Haramaya dry lake basin. Once these precious resource is lost due to misuse, uncomfortable and challenging environment would complicate life and enhance poverty (Alemayehu et al., 2007).

Generally speaking, the water resource of dry lake basin is getting exploited for different purposes and by different users even outside its boundary. As this kind of competition for a limited supply of water increases, it becomes increasingly important to clearly communicate how water is being used and how water resource developments will affect the present use patterns (Molden, 1997a).

Based on the aforementioned critical reasons, rehabilitation of the lake should be given first priority so as to sustain the livelihoods in the area. However, rehabilitation of the lakes is a long process that requires dedication of the local people, experts and policy makers and can be achieved through integrated approach that

needs more than two decades (Alemayehu et al., 2007). This study was, therefore, a starting point for the so-called long process and the main objective was focused on reviewing and evaluating the existing irrigation water management and developing an alternative intervention which could optimize the withdrawal of water for irrigation purposes.

MATERIALS AND METHODS

The study area

Lake Haramaya catchment is one of the catchments in the Eastern Ethiopia found in Haramaya District, Eastern Hararghe zone, Oromia Regional state (Tadesse et al., 2010). The catchment is situated on the main road from Addis Ababa to Harar town at a distance of 505 km from Addis Ababa and 20 km Northwest of Harar town. It is situated at 9° 23' to 9° 26' North of latitude and 41° 59' to 42° 02' East of longitude.

The total area of the catchment is 5032 ha and encompasses a small part of Haramaya town, the Haramaya university campus, three pas (Damota, Ifa-Bate and Tiji-Gebissa) fully and another two partially, Ifa-Oromia (90%) and Gubi-Selama (10%) (Setegn et al., 2011). According to the East-Hararghe zone planning and economic development department, Haramaya District with a total of 18,800 stands fifth after Girawa, Deder, Bedeno and Meta districts in its population size (Senti et al., 2014). The livelihood of the community in Lake Haramaya catchment is mainly based on mixed farming, that is, cropping and livestock production (Muleta et al., 2006).

Based on the agro-climatologically classification, Haramaya woreda has Woina Dega (Wet and cool, 70%) and Kolla (dry and hot 30%) areas. The annual rainfall distribution record indicates that the area receives a bimodal rainfall type with the mean annual precipitation of 751 mm (Alemayehu et al., 2007). According to Muleta et al. (2006), the dry period (less than 30 mm per month) extends from October to January inclusive; December with 9 mm is the driest month. The wet season starts in February (37 mm) and extends up to March (67 mm). The monthly rainfall is more than 100 mm from April to September, except June (65 mm). The wettest month is August with an average rainfall of 144 mm. The maximum and minimum mean annual temperatures for the area are 23.8 and 9.6°C respectively (Tadesse et al., 2010). The mean monthly relative humidity before the year 2003 falls between 53 and 75% (Alemayehu et al., 2007).

Lake Haramaya catchment covers areas with elevation ranging between 1980 and 2343 m.a.s.l. About 71% of the catchment is characterized by undulating and rolling topography (Muleta et al., 2006). On the basis of USDA soil textural classification scheme, the soil in the watershed was grouped into four different classes: clay (14.6 km²),

clay-loam (25.7 km²), sandy clay loam (6.1 km²) and sandy-loam (5 km²) (Tadesse and Abdulaziz, 2009). The six land use types comprised in the study area are cultivated land (78.3%), grazing land (7.6%), forest (0.6%), settlement (4.5%), shrub (4.6%) and swampy area (4.5%) (Tadesse and Abdulaziz, 2009). The major crops grown in the area under irrigated conditions are chat and vegetables (potato, lettuce, carrot, onion, tomato and cabbage). Sorghum and maize were grown under rain-fed conditions (Setegn et al., 2011).

RESEARCH METHODOLOGY

Water abstracted for irrigation

The type of irrigation practiced at dry Haramaya Lake basin is small holder irrigation system from which data about the amount of irrigation water abstraction is barely available. Thus, the amount of water withdrawal for irrigation purposes was determined through field investigation. The types of irrigated crops, average number of irrigations, irrigation time, pumping rate and size of irrigated areas was collected through interviews and focal group discussion. Finally, the irrigation depth was obtained by analyzing the data on rate and duration of pumping and the size of farmers plot irrigated at a time.

Soil moisture status

Soil moisture status was measured to determine the amount of moisture that can be retained by the soil and available for crop uptake in the irrigation fields. Soil samples were collected for analysis of moisture content at field capacity and permanent wilting point. The sampling was done in a way that adequately considers the lateral and vertical variation in soil properties according to the standards reported in different literatures (FAO, 1979b; Walker and Skogerboe, 1987; Yihun et al., 2013). Accordingly, four samples at an interval of 30 cm (0 to 30, 30 to 60, 60 to 90 and 90 to 120) cm respectively were collected from each sampling point. The moisture content at field capacity and permanent wilting point was determined in the laboratory using Pressure plate apparatus according to the procedure outlined in Burk and Dalgliesh (2012).

Crop and irrigation water requirement

Evapo[transpiration was estimated by the crop coefficient - reference evapo-transpiration (Kc-ET_o) procedure. In this method, reference evapo-transpiration (ET_o) was first computed for a reference crop (usually grass or alfalfa) and then multiplied by an empirical crop coefficient (Kc) to estimate crop evapo-transpiration (ET_c) (Smith et al.,

1998). Due to the fact that ET_o represents nearly all effects of weather, Kc varies predominately with specific crop characteristics and only a small amount with climate; the Kc-ET_o approach has got widespread acceptance and usefulness (Furi, 2005; Senti et al., 2014).

The reference evapotranspiration (ET_o) was computed using FAO Penman-Monteith method imbedded in CROPWAT, a computer model developed by FAO (Food and Agriculture organization). The Penman - Monteith ET_o is a function of the four main factors affecting evaporation, namely temperature, solar radiation, wind speed and vapour pressure (Allen et al., 1998). This method was selected because it uses standard climatic data that can be easily measured or derived from commonly collected weather data (Muleta et al., 2006). Weather data for the Haramaya station was collected from the National Metrological Agency.

Information on the type of crops grown in the area, first and last planting and harvesting dates of the crops, present cropping pattern, crop intensity and crop yields was obtained through field observation, interview with Haramaya Wereda agronomy experts, development agent, farmers and farmers' association. Standard values for crop parameters of the major crops grown in the study areas including crop coefficients, rooting depths, depletion levels, yield response factors were obtained from Allen et al. (1998) as embedded in the CROPWAT model with some modification based on local conditions.

The crop water requirement and the amount of water required to compensate the evapo-transpiration loss from the cropped field was determined employing CROPWAT model having the crop and soil data as inputs. Irrigation water requirement, the difference between the crop water requirement and effective precipitation was computed with the same computer model, CROPWAT.

Water productivity

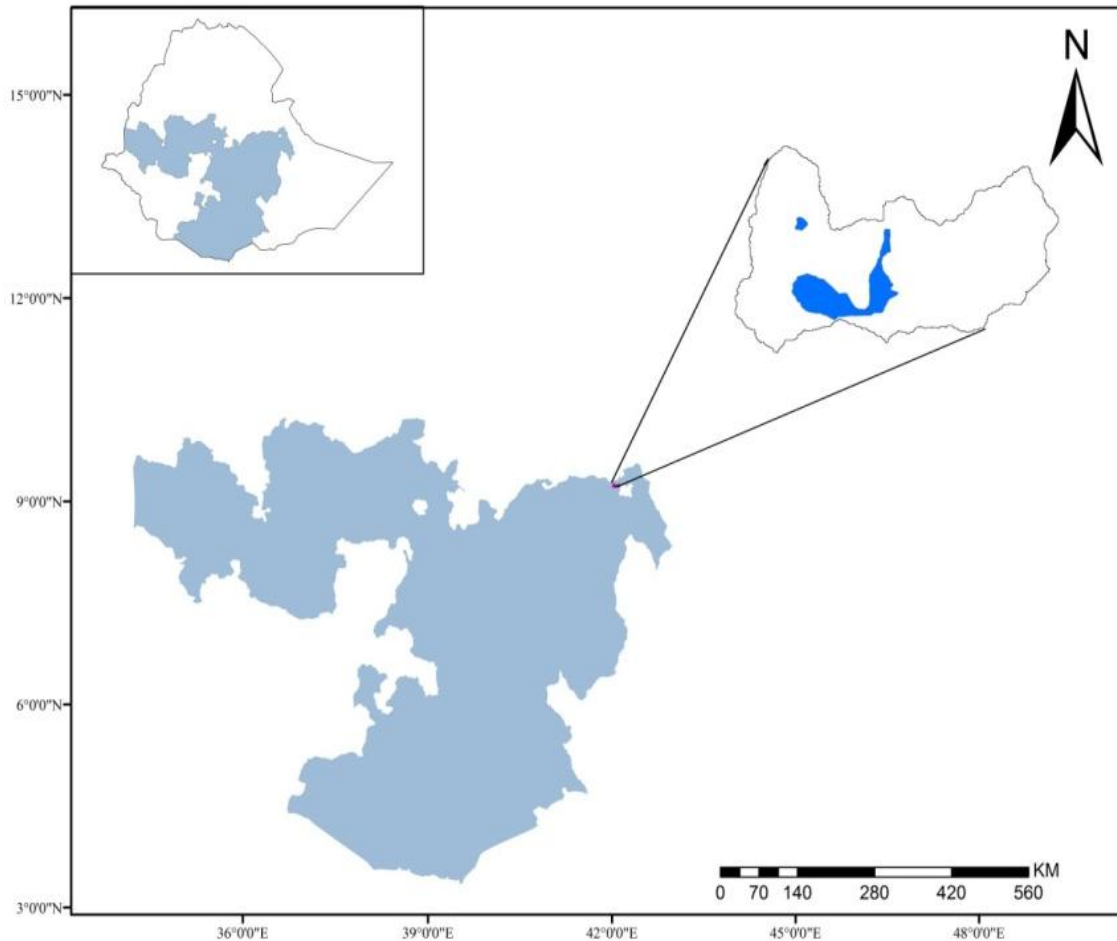
Water productivity is the physical mass of production or economic value of production to quantum of water used or delivered for the production (Molden, 1997b). The denominator of water productivity calculations may be the amount of water evapo-transpired or the water input diverted from sources for irrigation (Molden et al., 2003). In this study, water productivity (WP in Kg/m³), was computed as the harvest yield of crop over total seasonal irrigation water applied to the field given as:

$$WP = \frac{Y}{I_g} (Kg.m^{-3})$$

Where Y is the harvested yield of crop (kg) and I_g is the total seasonal water applied to the field (m³).

Table 1: Soil water characteristics of the study area.

Soil type	Moisture content		Available water (mm/m)	Infiltration rate (mm/h)
	Field capacity	Wilting point		
Loamy fine sand	0.16	0.10	62	30-35
Sandy loam	0.24	0.13	109	20-30
Sandy clay loam	0.32	0.21	107	15-20
Light clay	0.33	0.26	100	5-10

**Figure 1:** Location map of Dry Haramaya Lake Basin.

RESULTS AND DISCUSSION

Soil and soil water properties

The soil properties required for irrigation water scheduling are the available water and infiltration rate of the soil. The water was determined as a function of the soil moisture at field capacity and permanent wilting point. The infiltration rate corresponding to the different soil types was adopted from Brouwer et al. (1988) and Johnson (1963). Table 1 shows the values of soil moisture at field capacity and wilting point, available water and the infiltration rate for different soil types in the study area.

Traditional irrigation system

Irrigation depth

The irrigation depth was obtained by analyzing data on rate and duration of pumping and the area of farmers plot irrigated at a time. Interview and measurements were made in farmers plot located in different parts of the dry Haramaya Lake basin (Figure 1) specifically from Damota, Finkile and Tuji Gebisa. From field measurements, it was found out that the actual capacity of pumps used by the farmers differ from farmer to farmers due to the type and efficiency of the pump. For this study, an average value of

Table 2: Average irrigation depth calculation for carrot.

Location	Code of farmer	Plot size (m ²)	Duration of pumping (min)	Volume of applied irrigation water (m ³) Col 4 * 0.1848	Application depth (mm) Col 5/Col 3	Plot size × application depth Col 3*Col 6
Tugi Gabisa	MAB	7	2	0.37	52.80	369.6
	MAD	3	2	0.37	123.20	369.6
	CAB	7.5	4	0.74	98.56	739.2
	ROU	5	2	0.37	73.92	369.6
Finkile	MSH	6	3	0.55	92.40	554.4
	AAH	12	3	0.55	46.20	554.4
Damota	BAD	13.5	10	1.85	136.89	1848
	MEI	6.75	2	0.37	54.76	369.6
	Total	60.75	Average		=5174.4/60.75 = 85	5174.4

Table 3: Average irrigation application depth under traditional irrigation method.

Type of crop	Average application depth (mm)
Carrot	85
Beet root	87
Onion	34
Cabbage	129
Potato	35
Tomato	35

0.1848 m³/min was considered. The duration of pumping also varies from one farmer to the other even for the same crop and plot size. Hence, a weighted mean method (example calculation for Carrot is given in Table 2) was adopted to get the average irrigation application depth. The irrigation depth for other crops was obtained with the same approach and the results summarized in Table 3.

Table 2 shows that the irrigation water application varies significantly from one farmer to the other. For instance, in Tuji Gabisa, 0.37 m³ of irrigation water was applied for 7 m² plot by farmer MAB while the same amount of water was applied for 3 m² plot by farmer MAD.

Seasonal irrigation water applications

The seasonal water consumption of crops under the traditional irrigation system is very crucial in determining the water withdrawal for irrigation and assessing the performance of the irrigation system as well. In this study, the total seasonal water application was estimated by considering the duration of growth period and the irrigation intervals (Table 4).

Table 4 shows that the irrigation cycle/frequency depends on the growth stage of the crop while the irrigation depth is the same throughout the growing period. The irrigation frequency is short during the initial crop stage while it is longer during the late or harvesting

stage. The irrigation depth and/or the irrigation interval vary with the crop development (Brouwer et al., 1989). At the beginning of the growing season, the irrigation depth should be small and given frequently due to the low evapo-transpiration of the young plants and their shallow root depth.

During the mid season, the irrigation depth should be larger and given less frequently due to high evapo-transpiration and maximum root depth. In this regard, the attempt to make the irrigation frequency longer as the crop gets developed is appreciable. However, modification is needed with regard to balancing the irrigation frequency

with irrigation depths. The irrigation scheduling of the traditional system was made without considering the soil properties. As a result, the irrigation interval was very small making more and more water to be stored on the upper few centimeters of the soil profile which leads to higher water losses due to evaporation (Table 4). Table 5 shows the irrigation water application for different irrigated crops in the catchment.

Table 5 shows that the maximum irrigation depth in cabbage is 4891 mm per growing season while the lowest appears at beetroot which is 563 mm per growing season. Although its total water application is too high, the relatively higher water application for cabbage than the other vegetables in the study area is an agreement with the directions given by Shanmugavelu (1989).

Table 4: Growth period and irrigation frequency of crops under the traditional irrigation system.

Crop	Growth period	Duration (days)	Irrigation cycle (days)
Cabbage	Initial	11	3
	Dev	81	3
	Harvest	29	4
	Total	121	
Beetroot	Initial	7	5
	Dev	36	9
	Harvest	15	14
	Total	58	
Carrot	Initial	23	5
	Dev	70	5
	Harvest	23	13
	Total	116	
Onion	Initial	28	3
	Dev	67	4
	Harvest	11	7
	Total	106	
Potato	Initial	25	3
	Dev	51	4
	Harvest	21	7
	Total	97	
Tomato	Initial	13	3
	Dev	41	4
	Harvest	16	7
	Total	70	

Water productivity

The water productivity of the traditional irrigation system practiced in the dry Haramaya Lake basin is determined evaluating the performance of the system. Water productivity can be expressed in different terms. In this study, water productivity is obtained in terms of the mass of harvested crop per unit cubic meter of applied irrigation water (Table 6).

Table 6 indicated that potato and tomato had higher water productivity value of 5.60 and 5.56 kg/m³ respectively while cabbage recorded lower water productivity value of 0.69 kg/m³. This is mainly due to their difference in water requirements where cabbage consumes by far higher irrigation water than the others

while their harvested yield is fairly similar. Nevertheless, the water productivity of onion, potato and tomato lies well in the range as stated by Molden et al. (2010) where their water productivity ranges from 3 to 10, 3 to 7 and 5 to 20 kg/m³ respectively.

Water withdrawal for irrigation purposes

The amount of water pumped for irrigation purpose can be obtained by multiplying the depth of water applied in a season with its areal coverage. Table 7 gives the water withdrawal per unit hectare of land for different crops.

Table 7 points how much water is being withdrawn for irrigating unit hectare of vegetable crops with the

Table 5: Total seasonal water applications for different crops under the traditional irrigation system.

Crop	Irrigation depth	Applied Irrigation depth (mm)			
		Initial	Dev	Harvest	Total
Beetroot	87	122	348	93	563
Cabbage	129	473	3483	935	4891
Carrot	85	391	1190	150	1731
Onion	34	317	570	53	940
Potato	35	292	446	105	843
Tomato	35	152	359	80	590

Table 6: Water productivity under the traditional irrigation system.

Crop	Length of growing period (days)	Total depth of applied irrigation water (mm)	Plot size (ha)	Total volume of applied irrigation water (m ³)	Yield harvested (quintal)	Water productivity (kg/m ³)
Beetroot	58	563	0.125	704	11	1.56
Cabbage	121	4891	0.125	6114	42	0.69
Carrot	116	1731	0.125	2164	49	2.26
Onion	106	940	0.125	1175	51	4.34
Potato	97	843	0.125	1054	59	5.60
Tomato	70	590	0.125	738	41	5.56

Table 7: Water withdrawal under the traditional irrigation system.

Crop	Applied irrigation water (mm)	Water pumped per ha of land (m ³ /ha)
Beetroot	563	5,630
Cabbage	4891	48,913
Carrot	1731	17,314
Onion	940	9,403
Potato	843	8,429
Tomato	590	5,904

traditional system. In view of that, the water pumped out for cabbage production indicates a maximum value of 48,913 m³/ha which is nearly 50% of the sum of the remaining crops while the minimum water withdrawal of 5,630 m³/ha was practiced for beetroot.

ET Based irrigation

Water requirements

Based on the aforementioned inputs (used in scenario one), the water requirements of each crop were calculated using CropWat model (Table 8) considering 70% irrigation efficiency.

Obviously, the water requirement of all the crops dropped considerably when compared to the traditional irrigation system. The highest cut occurred in cabbage leading to a reduction from 4891 mm in the traditional system to only 380.5 mm (92% reduction) in the ET based followed by carrot reduced from 1731 to 367.8 mm (79%

reduction). On the other side, the smallest reduction occurred in tomato from 590 mm in the traditional irrigation system to 236 mm in the ET based irrigation system (60% reduction). Hence, it can be concluded that by shifting from the traditional irrigation system currently in use into ET based irrigation system, at least 60% water saving can be achieved for every vegetable crop in the study area.

Considering the irrigation systems detailed in two different scenarios; the second scenario that is, ET based irrigation betters the first scenario as it showed increase in water productivity by significant margin. Basically, water productivity can be boosted by improving the numerator and/or reducing the denominator or combination of them. In this case the water productivity in ET based irrigation is solely improved due to efficiency improvement in the process that is, reducing the amount of applied irrigation water. Of course, the authors believed that the harvested yield of the vegetable can be improved in the ET based irrigation system as it can help reduce the ill effects of excessive irrigation water applications on the field. This is

Table 8: Total seasonal water requirement for different crops under the ET based irrigation.

Crop	Etc (mm)	Eff rain (mm)	Irr. Req. (mm)
Beet root	194.7	21.1	175.3
Cabbage	440.9	59.9	380.5
Carrot	421.6	54.7	367.8
Onion	387.8	42.9	344.7
Potato	353.5	61.6	294.3
Tomato	257	23.5	236

Table 9: Water productivity of crops under the ET based irrigation.

Crop	Length of growing period (days)	Total depth of applied irrigation water (mm)	Plot size (ha)	Total volume of applied irrigation water (m ³)	Yield harvested (quintal)	Water Productivity (kg/m ³)
Beet root	58	250	0.125	313	11	3.51
Cabbage	121	544	0.125	679	42	6.18
Carrot	116	525	0.125	657	49	7.46
Onion	106	492	0.125	616	51	8.29
Potato	97	420	0.125	526	59	11.23
Tomato	70	337	0.125	421	41	9.73

Table 10: Water withdrawal under the under the ET based irrigation.

Crop	Applied irrigation water (mm)	Water diverted per ha of land (m ³ /ha)
Beet root	250	2,504
Cabbage	544	5,436
Carrot	525	5,254
Onion	492	4,924
Potato	420	4,204
Tomato	337	3,371

because the Haramaya groundwater is known for its highest sodium and bicarbonate contents which could significantly degrade the soil quality (Adhanom and Kibret, 2011). It was also reported by Adhanom and Kibret (2011) that the salinity level (ECe) of the irrigated soils at Haramaya was higher than the non-irrigated soils by as much 405.9% mainly due to the salts coming into the command area when irrigated from the groundwater. Yet, the production can be improved using different inputs like fertilizers, improved variety and technology which can further improve the water productivity in both scenarios.

Table 9 shows that the highest water productivity gain occurs in cabbage rising from 0.69 kg/m³ in the traditional system to 6.18 kg/m³ in the ET based irrigation system. The least water productivity improvement occurred in tomato rising from 5.56 kg/m³ in the traditional irrigation system to 9.73 kg/m³ in the ET based irrigation system. Similar to the case in the traditional system, the productivity levels are in line with the productivity level as indicated by Molden et al. (2010). Albeit, the water productivity level shifted from below range average in the traditional system to above range average in the ET based irrigation system considering the Molden et al. (2010) water productivity ranges as reference.

Table 10 depicts the water withdrawal under ET based irrigation system. In this regard, ET based irrigation outperforms the first scenario in water withdrawal (less water withdrawal). As shown Table 11, the extra water withdrawal under traditional irrigation compared to the ET based irrigation is as high as 800% in the case of cabbage and lowest extra water added was found in tomato which is 75%. At least 75% water can, therefore, be undoubtedly saved by only shifting from the traditional system to ET based irrigation method. Yokwe (2009) reported similar findings with the results of this study given in Table 10.

Conclusion

The study outlines the following points as conclusion:

- Soils of the study area lies under the loamy fine sand, sandy loam, sandy clay loam and light clay textural group.
- There is significant variation in the depth and volume of irrigation water among farmers indicating the absence of common irrigation practice in the study area. The short irrigation interval in the traditional system ensures that

Table 11: Variation of water diverted per ha of land (m³/ha) and water productivity (kg/m³) under traditional and ET based scenarios.

Crop	Water withdrawal per ha of land (m ³ /ha)			
	Traditional	ET based	Difference	Difference as percentage of the traditional
Beet root	5,630.0	2,504.0	3,126.0	125
Cabbage	48,913.0	5,436.0	43,477.0	800
Carrot	17,314.0	5,254.0	12,060.0	230
Onion	9,403.0	4,924.0	4,479.0	91
Potato	8,429.0	4,204.0	4,225.0	100
Tomato	5,904.0	3,371.0	2,533.0	75

water is continuously available on the top soil surface exposed to direct sun light which aggravates the evaporation loss.

- In general, the traditional irrigation system was characterized with unnecessarily higher seasonal irrigation water applications (as high as 4891 mm for cabbage), lower water productivity (as low as 0.69 for cabbage) and huge total water withdrawal that reaches on the average 11,650 m³/ha.

- With the ET based irrigation system, a reduction in the total seasonal water requirement by at least 60%, an increase in water productivity by at least 75% and a 73% reduction in seasonal water withdrawal for a unit hectare of land was achieved.

The existing poor irrigation water management is the failure of all stakeholders in the basin including the various governmental and non-governmental organizations working on water and water related activities, the Haramaya University and, of course, the farmers. This calls for immediate community awareness about the consequences of over exploitation on the future availability of water. It also suggests that priority as regards water resources management and irrigation be given to training and awareness creation for the farmers, wereda experts and development agents. Finally, for better water management and optimum irrigation water withdrawal, upgrading the existing traditional irrigation system into the ET based irrigation system is highly recommended.

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