Prospects and Constraints of Household Irrigation Practices, Hayelom Watershed, Tigray, Northern Ethiopia

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ABSTRACT

Constraints and prospects of hand dug wells related to household irrigation were assessed in Hayelom watershed (~1045 ha), by evaluating groundwater suitability for irrigation, soil quality and impact of intervention. 181 hand dug wells have come into existence in the watershed due to intervention and benefiting about 166 families.

Eight groundwater and twenty soil samples were tested to understand the suitability of groundwater and soil in the area. Impact of the intervention on livelihood of the household was assessed on the basis of the data obtained through questionnaire, and discussions held with focal groups and individuals. Water and soil samples were analyzed for major cations and anions, boron, pH and electrical conductivity and the data is computed both sodium absorption ratio and exchangeable sodium percentage.

The results suggest that groundwater is suitable for irrigation purpose and the soils are free from soil salinity and sodicity hazards. Introduction of new tree plants, improvement in the households feeding habits, income, and introduction and adoption of water lifting technologies are some of the changes observed in terms of prospects. On the other hand, spacing of hand dug wells, sliding of its walls, similar and simultaneous production of vegetable crops, wastage of land, maintenance of water lifting technology and water scarcity are some of the major constraints identified in the watershed. Intervention though undoubtedly has helped to improve the standard of life in the watershed, has introduced some of these constraints. Continuation of the irrigation activities in this virgin area is expected to bring changes in the quality of water and soil as well. It may emerge as a serious constraint in future if proper attention is not paid at this juncture.

Key words: Constraints, Groundwater, Hand dug well, Intervention, Irrigation, Soil quality.

1. INTRODUCTION

Water, the indispensable natural resource is broadly grouped into two categories, blue water and green water (Awulachew et al., 2008). Blue water is the water resources contained in rivers, lakes and accessible groundwater and green water is the rainwater stored in the soil and subsequently transpired and evaporated by plants. The scarcities and shortages forecasted in many reports refer mainly to the blue water and do not account for the potential of green water use in agricultural production. The latter, if well utilized through proper watershed management, it can make a great difference regarding the socioeconomic development in both up and downstream areas. In most of sub-Saharan Africa, the great bulk of food production is not related to blue water use but is in fact produced with green water in rain fed agriculture. For example, in Ethiopia, more than 90% of food is produced with green water in rain fed agriculture. Still, most research, like in all other African countries, is related primarily to blue water usage. This is based partly on an old paradigm promoted during the green revolution: by breeding better crops on irrigated land (or without regard for water needs) the world's food problems can be solved (Awulachew et al., 2008). Neither the breeding of better crops in irrigated land nor the management of rainwater for agriculture is done effectively in Africa. Despite the huge success of the green revolution (especially in Asia), the African continent remains behind the rest of the world in crop production and consequently, cannot meet the basic food needs of its population. The green revolution in Asia was primarily the result of i) improved soil fertility management, ii) the introduction of high yielding varieties, iii) better water management, including irrigation development with surface waters, groundwater and rainwater, and iv) favorable economic conditions arising from the high market price of agricultural produce (Awulachew et al., 2008). So, attention and investment in these areas have been very limited in Africa and the continent has largely been bypassed by the green revolution.

Although Ethiopia's water resource is large with 12 major river/drainage basins, about 111 billion cubic meters run off, and eleven major lakes comprising a total area of 750, 000 ha, very little of it has been utilized for agriculture, hydropower, industry, water supply and other purposes. Due to this so far only about 160, 000 ha (about 4%) of the potential irrigable land i.e. about 3.7 million ha has been developed in the country (Ministry of Water Resources, 2001).

Among various parts of the country, Tigray region is one of the area worst affected by frequent droughts. In Tigray, about 621,000 households, constituting about 75 %, of the total population of about four million is food insecure and seriously threatened by the droughts, which hit the region every 3-4 years (Hugo, 2003). Major climatic limitations for agricultural production are erratic rainfall, unpredictable monsoons, which often combined with intermittent dry spells that regularly threaten the survival of the crops, resulting in reduced production and food insecurity.

In order to reduce dependency on large amounts of assistance, the Regional Government four years ago, has geared itself with an ambitious goal to eradicate 88% of the food deficit. It has formulated a "Rural Development Strategy Plan" based on water, agriculture and cooperatives. Water harvesting with ponds and groundwater extraction by shallow wells was one of its main objectives, intended to increase the agricultural production during relatively good times and secure crop production during dryer years.

The above said plan was implemented in many areas in Tigray region since 2003 onwards. Hayelom watershed is one such area in Tigray region that has experienced the effects of intervention. Hence it is chosen to assess the prospects and constraints of household irrigation practices using shallow hand dug wells and to evaluate its impact on groundwater and soil quality. Like in other parts of Tigray, in Hayelom watershed, the households are extracting groundwater through hand dug wells and utilizing it for irrigation and livestock purposes since 2003. Though, the interventions have helped to produce different high value crops two to three times in a year, the benefits and challenges of such irrigation practices and its short term and long term effects have not been assessed properly. The presented paper tries to address some of such problems and provides solutions.

2. STUDY AREA

The study area, Hayelom watershed, is located in Tigray Regional State, Northern Regional State of Ethiopia, about 120 km northeast of Mekelle town, capital city of the Regional State. Geographically, it is found bounded between 545000 – 551000m E and 1547000 – 1553000m N, and has an aerial coverage of about 1045 ha (Fig.1). Topographically, undulating surface, flatlands and mountains characterize the study area. The surrounding mountains are characterized by gentle to steep slopes covered with scattered bushes. The elevation of the area ranges from 2140 m above mean sea level at northwest to 2290 m above mean sea level at the northeast part of the area.

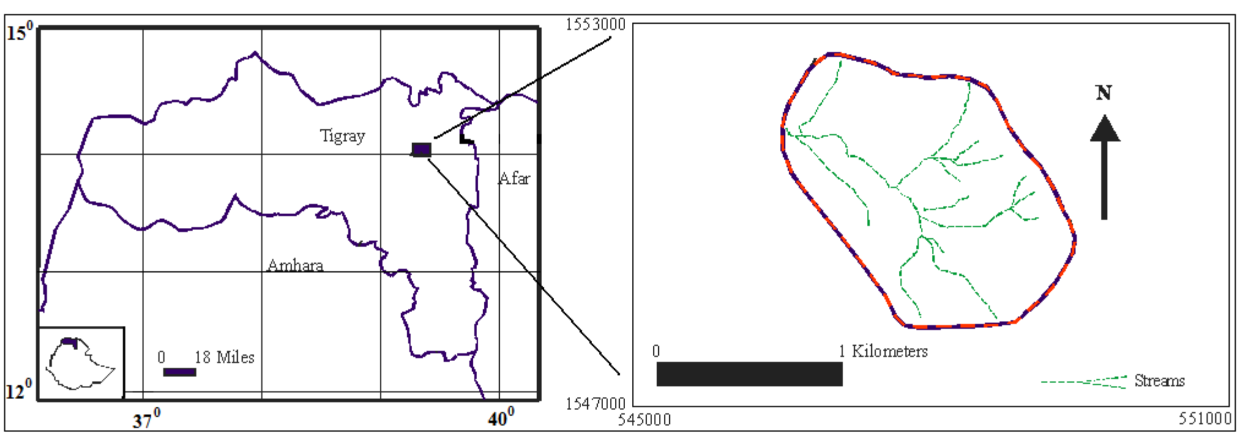

Figure 1. Location map of the study area (Disaster Prevention & Preparedness Agency, 2006).

The study area has been classified into five slope classes: 0 - 15 % (flatland), 15 - 30 % (gentle), 30 – 45 (intermediate), 45 – 60 % (slightly steep), and 60 – 75 % (steep). Steep slopes mostly characterized the northern, northeastern, eastern, southeastern, southern and southwestern parts of the study area whereas flatland and gentle slopes characterize the western, northwestern, and central parts of the study area. The drainage pattern in the study area is dendritic. Water flows from south, east and northeast to the center and forms one main river that drains the watershed northwest. This river then leaves the area, and joins the major river called Felegi Htsa outside of the study area. All the steams in the watershed are intermittent. The shape of the watershed is almost elliptical (Fig. 1).

2.1. Soil

Texturally the soil of the watershed is dominantly sandy type. In some areas, in the grazing land and gentle cultivated land, the soil texture gets loamy and sandy clay nature. The dominant soil color is white. However, in some very limited areas soils that have brown and grey colors are also common. Soil depth in the watershed varies with land cover. In the cultivated land, the thickness of soil with loamy texture and sandy type is more than 150 cm and the soil depth in the cultivated land around the hill ranges ranging from 50-100 cm whereas in the other land use types the depth of soil is generally below 50 cm.

Table 1. Land use type with their area proportion, slope range, soil depth, soil texture, soil color, and stoniness.

Land use	***Area (ha)***	***Slope range (%)***	***Soil depth (cm)***	***Soil texture***	***Soil color***	***Stoniness (%)***
Cultivated land	625.75	3-10	25-150	sandy	white	0-15
Grazing land	160	3-5	50-100	clay silt	brown	0-15
Bush land	57.5	20-25	<25	sandy	brown	15-30
Plantation	94.5	25-35	<25	sandy	brown	15-30
Homestead	12.25	5-15	<25	sandy	brown	15-30
Miscellaneous land	95	> 25	<25	sandy	white	>25
Total	1045					

2.2. Land use

Six major land use types were identified from the present land use during the field assessment made on the watershed (Table 1). These are cultivated land, grazing land, bush land, homestead, plantation, and miscellaneous land. Of these, cultivated land constitutes 59.9 %, which is the largest portion of the total area. The agricultural practice is largely undertaken in the slope range 0 -15 %. The major agricultural crops produced in the area are wheat, teff, sorghum, maize, barely and vegetable crops. Grazing land constitutes 15.3 % of the total area. Bush land, plantation, homestead, and miscellaneous land constitute 5.5%, 9.0%, 1.2%, and 9.1 % respectively of the catchment. The area that is named as "plantation" includes areas, which are covered with very scattered acacia trees, cactus and eucalyptus trees.

2.3. Vegetation

The vegetation cover of Hayelom watershed is sparse. Some artificial tree plants were available like Eucalyptus species on the farmer's household as well as around the grazing lands as wood lot. In the bush land, Acacia species are dominantly grown.

2.4. Climate

The mean annual rainfall of the watershed is 524.08 mm (Nata, 2003). The watershed is characterized by one rainy season, that is, the rainy months are contiguously distributed. This also means that there are two dry seasons during the year. The rainy season consists of six rainy months that range from April to September, and the small rains occur from April to June and in September. The big rains are in July and August with very high concentration in both months. During these six months rainy period 86.6% of the average annual rainfall occurs. The small rains account 24.9% of the average annual rainfall and 28.7% of the rains that occurred in the rainy period. The big rains account 61.7 % of the average annual rainfall and 71.3% of the rains that occurred in the rainy period. The watershed has not experienced moderate and high concentration of rainfall.

The watershed is also characterized by two dry seasons. The first dry season starts in January and ends in March. The second is from October to December. These dry seasons are characterized by the occurrence of low amount of rainfall, which is 13.4% of the average annual rainfall. The mean annual air temperature of the watershed is 18.1ºC, and the yearly average maximum and minimum temperature is 25.1ºC and 10.8ºC, respectively. The annual range of temperature is 3.7ºC (Nata, 2003).

3. HYDROGEOLOGY

The study area is comprised of Paleozoic sedimentary rocks, Enticho Sandstone and Edaga Arbi Tillite, and the recent alluvial sediments (Fig. 2A). Different rocks and unconsolidated sediments in the watershed, which behaves as aquifers, are classified in to two based on the type of permeability that they exhibit and the extent of the aquifer, 1) localized aquifers with intergranular porosity and permeability (unconsolidated sediments: alluvial sediments along the margins of the major rivers and their tributaries); and 2) less extensive aquifers with intergranular and fractured porosity and permeability (consolidated sediments: Sandstone and Tillite). The hydrogeological map of the area is shown in figure 2B.

Geological and hydrogeological characteristics of the rocks and unconsolidated sediments of the watershed are discussed below with a particular reference to their water storage and transmission capacities.

3.1. Sandstone

About half of the studied area is covered by sandstone. It outcrops in the northern, northeastern, eastern, southeastern, southwestern, western, and northwestern parts underlying a flat to steep slopes topographical areas. It is white, coarse grained, calcareous and contain lenses of siltstone, grit and polymict conglomerate with sub-rounded to well-rounded pebbles, cobbles and boulders. The boulders are mainly of granite and gneiss and scattered. It is highly fractured, jointed and weathered. Two sets of joints are prominent in sandstone showing N15ºE and N25ºW trends. The exposed thickness of the sandstone varies from 20 to 80 m.

As it was observed in the open hand dug wells, the average thickness of the weathered and fractured zones is about 4 m. Secondary porosity due to fracturing is significant in this unit. This in turn indicates its capacity for water transmission and provides good site for water supply. However, in some parts, it has a high degree of cementation that reduces its permeability and productivity. In general this formation can be considered highly potential aquifer in the flat land of the study area due to its secondary porosity and permeability and also its primary porosity, but in the steeply to gentle slope it act as a conduit rather than an aquifer.

3.2. Tillite

This unit is exposed in the southern part of the study area. It occupy steep slopes and cover small part, <1 % of the study area. It comprises of grayish, fine grained, fissile and thinly bedded shale with boulders of pink and gray granite and other basement rocks. It has a maximum exposed thickness of 20 m. Since, this unit is too small, it is not shown in the map. However, it is closely associated with Enticho Sandstone. Presence of considerable amounts of shale, silt and clay, and strong silty-clayey cement makes this unit completely tight and impervious. The Tillites have intergranular permeabilities that are very low. In some cases, however, the fractures impart an enhanced capability for groundwater flow and storage. Because of its location and its nature, Tillites are acting as conduits for water movement rather than forming water-bearing formation.

3.3. Alluvial Deposits

In the watershed, alluviums are found as thin strip along the margins of the major rivers and their tributaries. Though they occurs both in high- and low-lands, their relative abundance however is not uniform in the area. Towards the mountain front, eastern and southern parts of the study area, where steep topographic slopes exist and the gradient of the rivers is high, the alluvial sediments are thin and dominated by sub-angular to sub-rounded coarse grained particles with variable content of coarse grained sand. In the central and northwestern parts of the watershed, where the gradient of the rivers decreases down slope, the alluvial deposit is thick and consists of medium to fine grained sand with variable content of silt and clay.

This unit is overlying both the litho-units in the northeastern, eastern, southeastern, southern, central and northwestern parts of the study area particularly along the margins of the major and minor streams. It comprises of clay, silt, sand and gravel sized particles in different proportion and has an average thickness 1.50 m. In the central and northwestern parts of the study area, these deposits can be considered as potential water bearing formation due to their primary porosity and location whereas due to their location in the northeastern, eastern, southeastern and southern parts of the study area the alluvium act as a conduit rather than being an aquifer.

3.4. Groundwater Development

The investigated area is currently supplied mainly with groundwater from developed hand dug wells. The shallow, mostly unconfined and confined, aquifers in the thin alluvial covers and weathered and fractured upper parts of the rocks are exploited through these hand dug wells. They supply water daily for domestic, irrigation and livestock consumption.

3.4.1. Hand Dug Wells

During the field work about 181 hand dug wells have been inventoried. Most of them were constructed between 2003 and 2007 as part of intervention for the purposes of irrigation, domestic and livestock's uses. At present the households are benefiting from these by producing different high value crops twice to three times in a year. More than 95% of the total available hand dug wells are found concentrating around the streams (Fig. 2B). With the exception of few wells, which are closed and fitted with hand pump, most of them are open and equipped with pulley and treadle pump. There is no uniformity in the geometry of dug wells which vary from circular, rectangular, trapezoidal to irregular shapes. Diameter of the circular dug wells range from 3 to 7 m and some of the rectangular dug wells have dimensions up to 7 x 5 m. Generally, the depth of the wells ranges from 1.3 to 6.5 m. Few dug wells have masonry lining whereas majority are dry brick or stone lined.

The yield of the dug wells varies from 1 to 3 l/s. The discharge of a dug well is relatively low because (i) dug wells tap only the top or the next lower water bearing stratum, and (ii) water from dug wells can be withdrawn only at the velocity equal to or smaller than the critical velocity for the soil, so as to avoid the danger of well siltation. The depth of static water level varies from 0.2 - 6 m. The wells are rich in water during the rainy season and the water table (in the unconfined aquifers) becomes shallow while during dry season the majority of them will dry up.

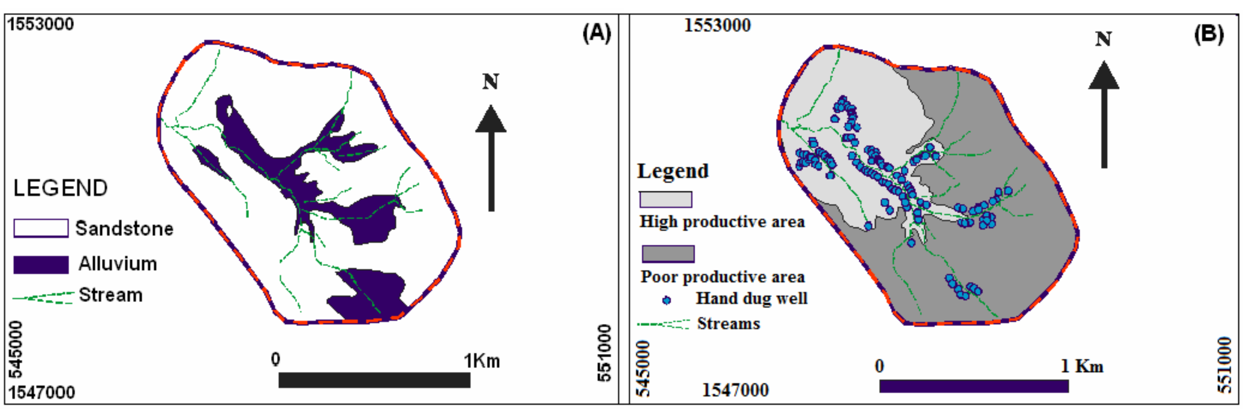

Figure 2. A) Geological and B) hydrogeological map of the study area.

In general, the yield characteristics of dug wells in the area depend upon several factors, namely: (a) landform - whether located in pediment, buried pediment or valley fill areas; (b) regolith - its thickness and permeability; (c) fracture characteristics of bedrock; (d) local groundwater regime: whether the well is located in groundwater recharge or discharge area; and (e) depth of water table and its fluctuation.

4. METHODOLOGY

4.1. Data Collection

To assess the prospective and constraints of household irrigation practice that use groundwater as a source in the study area, both primary and secondary data were collected in the field and from different organizations, respectively. On the basis of the field data both geological and hydrogeological maps were prepared using the topographic map (1:50,000) of the study area as base. The boundary of the watershed was delineated with the help of GPS and finalized later with the help of ArcView GIS 3.3 software. Data related to slope, land use, soil, geology and water points were collected in the field. Impact of the intervention on livelihood of the household was assessed through developed semi-structure questionnaires, and by conducting focal group, individual, formal and informal discussions. 30 people, including 4 female hand dug well beneficiaries were interviewed.

4.2. Sampling

To determine the quality of groundwater and soils, their utility for irrigation purpose, they were sampled systematically and analyzed. Initially inventory of all functional hand dug wells was carried out and about 16.6% of the beneficiaries were selected using random sampling technique for interview and collected the necessary data as per the questionnaire. During inventory, in situ measurement of electrical conductivity (EC) and temperature of the groundwater, and air temperature for each well was also recorded. Since the EC values were measured in situ at a temperature different from the standard 25°C, an adjustment of the EC values of groundwater was made by multiplying the respective measured EC value by the factor corresponding to the temperature at which the measurement was made.

To determine the number of water samples for chemical analyses, stratified and random sampling techniques were utilized. Eight water samples were selected randomly from different water classes, which were developed on the basis of quality classification of water for irrigation (Wilcox, 1955) using in situ and corrected EC values of groundwater. Similarly, 20 soil samples were collected from both the command area from where water samples were collected and also from the hand dug wells where water samples were not collected.

4.3. Analyses

All the water samples were analyzed in the Central Geological Laboratory, Ethiopian Geological Survey, Addis Ababa and soil samples in the Soil Laboratory of the Department of Land Resources Management and Environmental Protection, College of Dry Land Agriculture and Natural Resources Management, Mekelle University. Both the samples were tested for major cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}) and anions (CO_3^{2-}, HCO_3^{-}, Cl^{-}, SO_4^{2-}, NO_3^{-}) apart from boron (HBO_2), pH and EC (dS/cm).

On the basis of the data both Sodium Adsorption Ratio (SAR) and Exchangeable Sodium Percentage (ESP) were computed for each sample. SAR was computed using Na, Ca and Mg concentrations and ESP using the computed value of SAR for each respective soil sample. On the basis of the field data maps such as location, geological and hydrogeological were produced using ArcView 3.3 and CorelDRAW 12 software, and SPSS version 11 (SPSS, 2002) software for processing the data.

5. RESULTS AND DISCUSSION

Agriculture being the backbone of the country, its success story obviously depends on efficient management of the available water resources; maintenance of water and soil quality; and, planning suitable crops.

5.1. Groundwater and Soil Quality

5.1.1. Suitability of Groundwater

Irrigated agriculture is dependent on an adequate water supply of usable quality. Like portable for human beings, plants/crops also require a particular water quality. Changes in water quality due to changes in the source rock chemistry or selective enrichment of elements during evaporation of water or absorption by clay in the soil will be some of the known reasons which need proper monitoring. Either one or combination of the reasons generally cause the quality problems in the long run and become injurious to plant growth and affect production. Such changes in water and its suitability for irrigation are determined on the basis of the parameters like salinity, water infiltration rate, toxicity etc. In this study, FAO (1989) guidelines for interpretations of water quality for irrigation are used to evaluate the groundwater suitability for irrigation.

Table 2. Hydrogeochemical data, Heylom watershed, Tigray, northern Ethiopia.

S. No	Sample No.	pH	EC dS/m)	HCO_3	Cl	NO_3-N	SO_4	CO_3	Na	K	Ca	Mg	B	TDS	SAR
				mg/l											
1	ASSEM 2	8.16	0.905	233	17	15.1	26	0	15	15	57	9	0.47	620.3	1.8
2	EDW2	8	0.259	143	8	2.66	1	0	8	2	28	5	0.14	197.8	0.4
3	HDW1	8.3	0.715	325	57	25.9	28	0	37	4.3	68	21	0.14	566.3	1.0
4	HW1N	7.55	0.702	362	39	1.77	38	0	52	1	54	15	0.4	563.2	1.6
5	HW2N	7.54	0.486	233	17	15.1	26	0	15	15	57	9	0.14	387.2	0.5
6	TASP1	7.81	0.883	429	60	2.66	48	0	40	1	86	33	0.14	699.8	0.9
7	W260	8.12	1.192	224	148	0.89	193	0	125	1	63	25	0.27	780.2	3.4
8	W39	8.52	0.578	190	53	26.6	44	5	30	2	55	12	0.27	417.9	1.0

5.1.1.1. Salinity Hazard

The salt concentration is generally calculated using EC values. Among 8 water samples analysed, in five, the values are between 0.702 to 1.192 dS/m and in three below 0.7 dS/m (Table 2). Therefore, EC values indicate presence of two types of groundwater - 1) groundwater that is not hazardous and needs no restriction on use; and 2) groundwater that needs slight to moderate degree of restriction on use. The first type groundwater can be used for irrigation for almost all crops and for almost all kinds of soils. No soil or cropping problems will rise. Very little salinity may develop which may require slight leaching; but it is permissible under normal irrigation practices except in soils of extremely low permeabilities. To achieve a full yield potential using the second type, gradually increasing care in selection of crop and management alternatives are required.

5.1.1.2. Infiltration (Sodicity) Problems

An infiltration problem related to water quality occurs when the normal infiltration rate for the applied water or rainfall is appreciably reduced and water remains on the soil surface too long or infiltrates too slowly to supply the crop with sufficient water to maintain acceptable yields. Although the infiltration rate of water into soil varies widely and can be greatly influenced by the quality of the irrigation water, soil factors such as structure, degree of compaction, organic matter content and chemical make-up can also greatly influence the intake rate.

The two most common water quality factors that influence the normal infiltration rate are the salinity of the water and its sodium content relative to the calcium and magnesium content. High salinity water will increase infiltration. Low salinity water or water with high sodium to calcium and magnesium ratio will decrease infiltration. Both factors may operate at the same time. The infiltration rate generally increases with increasing salinity and decreases with either decreasing salinity or increasing sodium content relative to calcium and magnesium i.e. the sodium adsorption ratio (SAR). Therefore, the two factors, salinity and SAR, must be considered together for a proper evaluation of the ultimate effect on water infiltration rate.

Sample W260 which shows highest value for both SAR (3.4) (Table.2) and EC (1.192 dS/m) (Table 2) indicates that the groundwater from this well needs slight to moderate degree of restriction on use. The SAR values remain between 0.4 and 1.8 for the remaining seven samples and fall in one group though they are classified into two groups based on their EC. Thus, four samples ASSEM 2, HDW 1, HWIN, and TASP1 with EC values (in dS/m) 0.905, 0.715, 0.702 and 0.883, respectively, indicate no hazards of sodicity will arise if the groundwater from these four wells is considered for use. While the remaining three samples with EC values ranging between 0.2 and 0.6 dS/m suggest that the groundwater from these hand dug wells needs slight to moderate degree of restriction on use.

Groundwater ASSEM 2, HDW 1, HWIN, and TASP1 can be used for irrigation with little danger on almost all soils and for almost all crops except those that are highly sensitive to sodium. For example, sodium-sensitive crops such as stone-fruit trees and avocados which may accumulate injurious concentrations of sodium. On the other hand, groundwater EDW2, HW2N, W39 and W260 are hazardous for use on fine textured soils because they will have high cation-exchange capacity. This water may be used on coarse textured or organic soils with good permeability.

5.1.1.3. Toxicity Problems

As it has been explained above, SAR values were computed for all the analyzed eight samples. With the exception of sample W260 (SAR = 3.4), in all the remaining samples the SAR values are well below 3, indicating no sodium toxicity will rise by using the groundwater from these hand dug wells for surface irrigation. In the sample W260, however, the computed SAR value suggests the necessity of slight to moderate degree of restriction on use of the groundwater from this hand dug well for surface irrigation. The likelihood of sodium toxicity hazards is high if the groundwater from this hand dug well is considered for surface irrigation use.

Toxicity in terms of chloride is also not a serious problem in the watershed except in one well (W260) where chloride toxicity hazard is high if considered for irrigation (Table 2). Boron, though one of the sensitive elements in terms toxicity, its values being < 0.7 mg/l (Table 2), do not indicate any problem in the area.

5.1.1.4. Miscellaneous Problems

Bicarbonate, although not ordinarily thought to be a toxic ion, is reported to cause zinc deficiency in rice. According to Mikkelson (FAO, 1989), bicarbonate in excess of 140 mg/l (2 meq/l) in the water used for flooding and growing paddy rice is reported to cause severe zinc deficiency. Though, rice is not a common crop in the area, in future, if it is considered as an alternative crop and groundwater is considered for irrigation, then bicarbonate level in the applied water must be considered to cope with zinc deficiency and production. This is generally rectified by adding zinc to soil before flooding or at the time of earliest appearance of the chlorosis. Actual zinc of 8 to 10 Kg/ha from zinc oxide or zinc sulfate is surface applied to remain in the upper 5 to 10 cm of soil (FAO, 1989).

Nitrate (NO_3 - N) concentrations in the in area being <26.6 mg/l (<5meq/l) (Table 2) do not pose any serious problems. Nitrogen in irrigation water is generally beneficial to most crops but may cause problems for some. Nitrogen in the irrigation water is readily available and if present should be considered as an important part of the fertilizer program. For most crops, this nitrogen is equivalent to fertilizer nitrogen and should be included in the total nitrogen planned for applications. For few crops, however, the added nitrogen from the water may be too much and result in excessive and vigorous growth, delayed or uneven maturity, and reduced quality. These sensitive crops include apricots, grapes, sugar beets and cotton and others.

The acidity or basicity of irrigation water is expressed as pH (< 7.0 acidic; > 7.0 basic). The normal pH range for irrigation water is from 6.5 to 8.4. Abnormally low pH's are not common in the study area, but may cause accelerated irrigation system corrosion where they occur. The measured pH values of the groundwater of the watershed, with the exception of sample W39, are laying within the normal pH range for irrigation water. The groundwater from sample W39 has a pH value of 8.52, which is a little bit higher than the normal range. In general, from pH point of view the groundwater of the watershed is safe and can be used for irrigation.

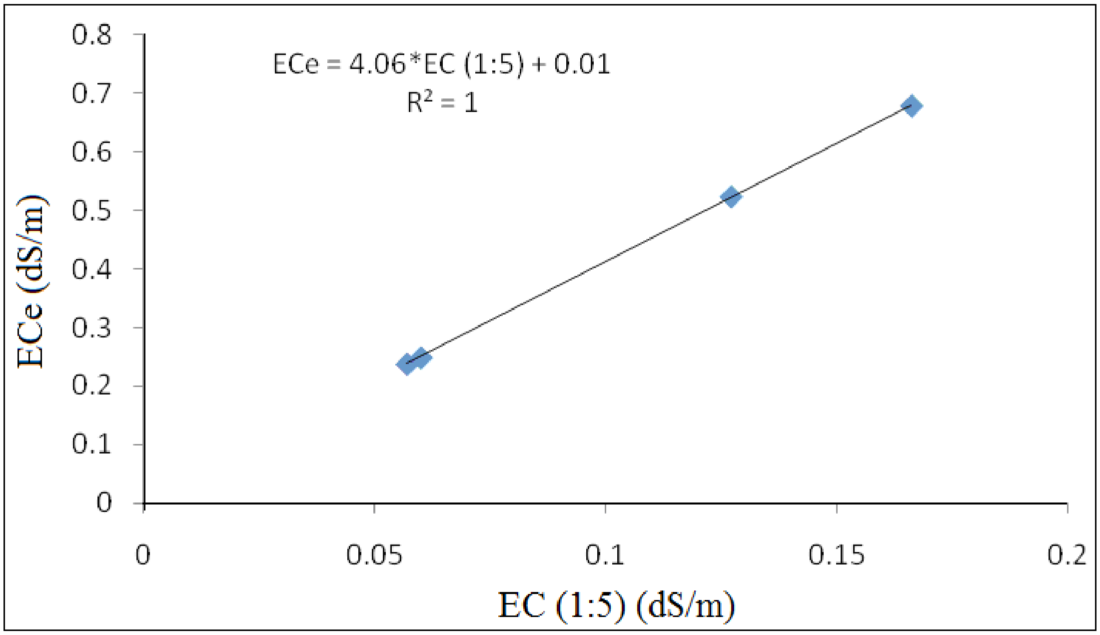

Figure 3. EC (1:5) versus ECe, soil samples, Heylom watershed.

Table 3. Summarized results of the analyzed soil samples, Heylom watershed, Tigray.

S.No	pH	EC 1:5) (dS/m)	ECe (dS/m)	Cations (meq/100 gm soil)				Calculated		Anions (meq percent/100 gm soils)				
				Na	**K**	**Ca**	**Mg**	**SAR**	**ESP**	**Cl**	**HCO_3**	**CO_3**	**B**	**SO_4**
SS1	6.6	0.229	0.942	0.124	0.021	0.152	0.079	0.366	2.514	0.099	1.1	0	8	
SS2	7	0.057	0.238	0.089	0.009	0.139	0.057	0.396	2.572	0.043	0.3	0	9	0
SS3	6.9	0.038	0.158	0.045	0.012	0.126	0.053	0.415	2.609	0.03	0.33	0	8	
SS4	7.3	0.123	0.511	0.059	0.027	0.153	0.063	0.378	2.537	0.037	1.16	0	8	
SS5	7.4	0.224	0.929	0.132	0.025	0.159	0.071	0.366	2.514	0.049	1	0	11	
SS6	7.2	0.238	0.983	0.183	0.006	0.174	0.086	0.344	2.471	0.046	0.85	0	12	
SS7	7.5	0.049	0.203	0.163	0.013	0.139	0.054	0.4	2.58	0.041	0.45	0	10	11.73
SS8	7.4	0.060	0.249	0.169	0.012	0.14	0.055	0.397	2.574	0.021	0.2	0	13	
SS9	7.1	0.821	3.58	0.327	0.024	0.211	0.082	0.325	2.434	0.037	0.7	0	12	
SS10	7.3	0.049	0.201	0.162	0.012	0.139	0.053	0.401	2.582	0.018	0.1	0	11	
SS11	7.4	0.166	0.679	0.199	0.012	0.177	0.063	0.358	2.498	0.046	1	0	10	
SS12	7.2	0.137	0.567	0.174	0.016	0.171	0.059	0.366	2.514	0.039	0.85	0	7	15.77
SS13	7.1	0.074	0.305	0.178	0.014	0.155	0.061	0.378	2.537	0.025	0.67	0	10	
SS14	7.3	0.119	0.493	0.171	0.022	0.174	0.064	0.36	2.502	0.035	1.05	0	8	
SS15	7.2	0.086	0.356	0.169	0.007	0.159	0.062	0.373	2.527	0.019	0.32	0	11	
SS16	7.1	0.073	0.304	0.169	0.007	0.185	0.058	0.356	2.494	0.035	0.65	0.2	10	16.2
SS17	6.4	0.041	0.171	0.165	0.008	0.182	0.059	0.357	2.496	0.035	0.9	0	11	
SS18	6.6	0.127	0.524	0.171	0.006	0.185	0.066	0.35	2.483	0.035	0.9	0	11	
SS19	7.3	0.145	0.599	0.241	0.014	0.193	0.072	0.341	2.465	0.035	1.15	0	11	
SS20	7.3	0.128	0.532	0.209	0.005	0.172	0.063	0.363	2.509	0.034	0.7	0	13	
Av.	7.13	0.149	0.626	0.16	0.01	0.16	0.06	0.37	2.52	0.04	0.72	0.01	10.20	10.93

5.1.2. Suitability of Soil

5.1.2.1. Soil Salinity

To assess the extent of salinity, soil samples from the command area of the wells were collected and analyzed for EC (1:5). The minimum and maximum EC (1:5) measured value was 0.038 dS/m at 25°C and 0.821 dS/m at 25 °C, respectively, with a mean EC (1:5) value of 0.149 dS/m at 25 °C. Moreover, the electrical conductivity of saturation extracts of the soil paste (ECe) was determined by taking representative samples and plotting these values against the EC (1:5) (Fig. 3), and the corresponding regression equation is ECe = 4.06*EC (1:5) + 0.01, (R^2 = 1). Therefore, the corresponding minimum and maximum ECe value was 0.158 dS/m at 25 °C and 3.58 dS/m at 25 °C, respectively, with a mean value of 0.626 dS/m at 25 °C.

In general, considering the average electrical conductivity, the soils of the command area have low salinity content (ECe < 2 dS/m at 25 °C) and are considered as salt free soils.

5.1.2.2. Soil Sodicity

Alkali hazard or sodium hazard was evaluated based on the calculated parameters of Sodium Adsorption Ratio (SAR) and Exchangeable Sodium Percentage (ESP). SAR is the proportions of sodium to calcium and magnesium. For all the analyzed soil samples, SAR was computed. Accordingly, the calculated SAR values range from 0.325 - 0.415 with an average of 0.37 ± 0.02 (Table. 3). By convention, a soil with SAR value greater than 13 is considered as sodic soil (Soil Science of America 1984, cited in Janzen, 1993). In the study area, all the computed SAR values are well below 13. Therefore, the soil of Hayelom area is free from sodic hazard.

Exchangeable Sodium Percentage (ESP), the proportion of exchangeable sodium to cation exchange capacity multiplied by 100%, was also considered as a parameter to evaluate the extent of sodicity of soils. Soil with more than 15 ESP associated with pH value of 8.5 and above is considered sodic (Brady, 2002).

ESP value for each soil sample was computed on the basis of its SAR value. There are various relations developed between SAR and ESP. According to USSL staff 1954 cited in Levy (2000), the soil ESP can be estimated from SAR of saturated paste extracts using an empirical relationships of ESP= 1.95 SAR + 1.8, when more dilute extracts are used, such as 1:5 (soils: water) ratio. ESP values thus obtained range between 2.434 and 2.61 with a mean of 2.52 ± 0.04

(Table 3). pH for each soil sample was measured in the laboratory. The values rang from 6.4 to 7.5 with a mean value of 7.13 ± 0.3.

Generally, according to USDA soil classification, a soil with electrical conductivity of saturation extracts (ECe) less then 2.0 dS/m at 25°C, ESP less than 15%, SAR less than 13 and pH less than 8.5 are classified as normal soil. Therefore, the soils of the study area are normal soils. Further, the irrigated land is also free from white efflorescence as observed during field work.

5.2. Impact of Intervention

Since 2003, the intervention has brought many changes in many areas in Tigray region. Studies in this regard related to impact of the intervention are limited so far. One such study by Nata et al. (2008) carried out in Debrekidane watershed in Hawzein Woreda has tried to show the opportunities and constraints due to the intervention. The presented paper also tries to highlight the same related to Hayelom watershed and discussed them below.

5.2.1 Prospects of Utilization of Hand Dug Wells

5.2.1.1. Households Job Opportunity

To assess the status of irrigation practices using hand dug wells in the watershed, 30 households were selected at random and interviewed. The proportions of the interviewed are 13% female and 87 % male headed households and the family size of the interviewees is about 6.87 (or 7).

Table 4. Members of households involved in irrigation activities, Heylom watershed, Tigray.

Full time labor		*Part time labor*		*Family Size*		*Households*	
Male	***Female***	***Male***	***Female***	***Male***	***Female***	***Male***	***Female***
39	23	29	33	106	100	26	4
19%	11%	14%	16%	51%	49%	87%	13%
30%		30%		100%		100%	

Irrigation is considered as a job opportunity by the households in the area. As a result, the members of the households involve full time/part time in the irrigation activities as a labor. From the total number of the household, 19% male and 11% female are involved in full time labor and 14% male and 16% female involved in part time respectively. Form the total population of the interviewed households, only 60% (124) are involved in the irrigation activities whereas the remaining 40% (82) are not completely involved because they not active work force of the households (Table 4). On the whole, the irrigation activities, initiated by the intervention, using groundwater from hand dug wells have created job opportunities for the farmers living in the watershed.

5.2.1.2. Improves Households Feeding Habit and Income

Before the introduction of hand dug wells in the watershed, the household's agricultural production was totally rain dependant. According to the responses of the interviewee, due to very small farmland holdings and erratic and unreliable rainfall, on an average, the households harvest was able to meet the food demands of the household only for about 4 to 5 months in a year provided rainfall distribution is proper. The remaining food gap was supplemented by a combination of activities including food purchasing from the market or participation in government and non-government relief programs like Food for Work or Cash for Work.

After intervention, the farmers have overcome this challenge by producing food grains/vegetables more than once in a year. The farmers currently practicing both complimentary and supplementary irrigation using the groundwater from hand dug wells. According to the respondents, the dominate crops grown under present irrigation practices are onion (38%), green paper (21%), maize (17%), tomato (8%) and other vegetables and spices (16%) (Fig. 4).

Vegetables, fruits and others which were only produced in the rainy season in a limited amount earlier have changed to abundant production through out the year. This enabled the farmers to get additional food stuffs and besides that has improved the households feeding habit as well. In addition, through sales they also earn income through out the year.

5.2.1.3. Introduction of Water Lifting Technologies

Use of motorized water pump and treadle pump as part of water lifting technology has started in the area following the introduction of hand dug wells. Treadle pump being cheap ($ 71) and easy to handle, it has become the choice of most of the farmers in the area. Further, they get money on credit basis. By adopting these water lifting technologies, the households, depending on the availability of water and land, have increased their land size for irrigation. Out of 30 respondents, 80% are using treadle pump, 0.6% motor pump and 19.4% manual pulley system. Before the adoption of treadle pumps, a household was irrigating on an average about 445.86 ± 325.43 m^2 lands. Whereas after the introduction the average irrigated farm land size of a household is about

2, 387.59 ± 1, 562.37 m^2 with a mean increment of 1, 941.73 m^2. This new trend even enabling the farmers to irrigate additional lands from others either by negotiations and/or by renting particularly from those who do not have hand dug wells or those who do have hand dug wells but are not able to work. This trend is contributing for higher food production in the area.

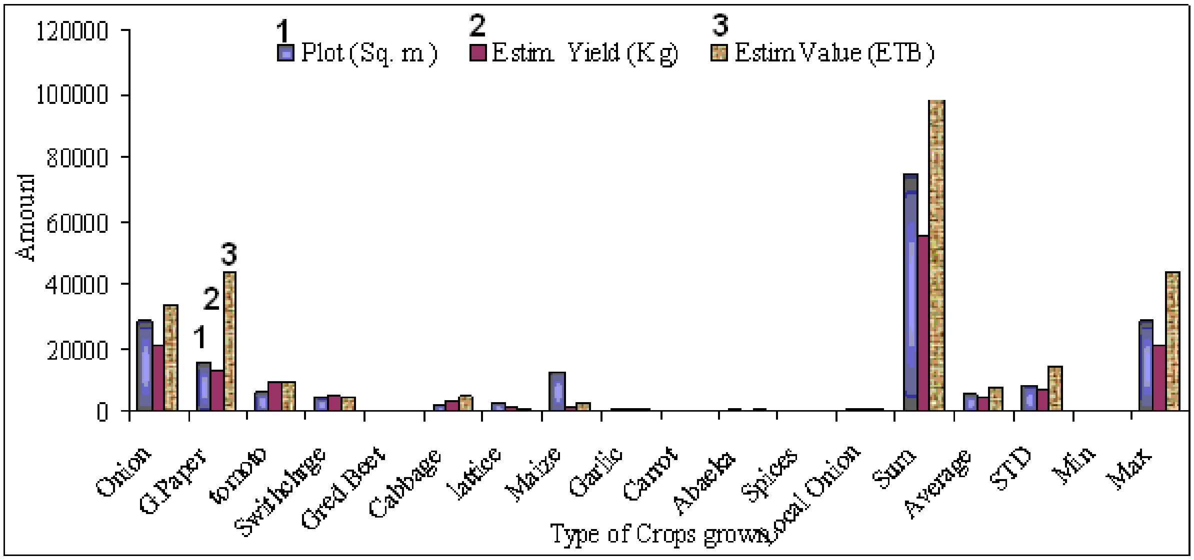

Figure 4. The type of crops, size of irrigated farmlands and yield in the Heylom watershed.

5.2.1.4. Diversification Opportunity

Availability of groundwater is creating an opportunity for the intervention to go for new varieties of tree plants that were not found before in the watershed. According to the respondents, about 567 (57%) fruit trees, 60 (6%) fodder trees (leucaenia leucocephala, Sesbania sesban) and 368 (37%) other trees were planted by the households. The fruit trees planted are Guava, Citrus spp (Lemon and Trengo), Gesho (Rhmnus prenoids) and Orange, constituting 32%, 23%, 16% and 9% from the total respectively. The number of fruit, fodder and other plants planted by households are 19, 2 and 12 respectively, with a total of about 33 per household.

5.2.1.5. Recharging Measures for the Enhancement of Discharges

In Hayelom watershed, the moisture harvesting practices are exercised in the upper catchments as well as on the farmlands in the lower catchments. The practices of physical and biological soil and water conservation measures are implemented through free mobilization of the community for 20 working days per annum. Besides, to rehabilitate the environment, implantation of soil and water conservation was practiced through Food for Work program.

The introduction of moisture harvesting practices reduces the runoff and increases the contact time of water and land and then increase infiltration rate to the ground. So far about 4199.704 km terraces or bunds are constricted till now in the area. By improving the upper catchment areas through these mechanisms the recharge opportunities for groundwater have increased significantly in the study area.

According to the community observation and remark, the availability of groundwater was sensed and observed after a few years of physical and biological soil and water conservation measures were implemented in the area. According to the response of the respondent and field physical observation, the rise up of groundwater in the hand dug wells and the reappearance of former springs and swampy areas are some of the indicators for the augmentation of groundwater. Besides, as part of soil and water conservation practices in the watershed, the households undertook plantation of tree seedling on homestead, gully, farmlands, and community lands. This is an opportunity for the expansion of agroforestry in the watershed.

5.2.2. Constraints

Identified major constraints of the intervention are spacing of wells, wells wall sliding, wastage of lands, maintenance of water lifting technology, market and water scarcity.

5.2.2.1. Spacing

Generally the sites of the wells lie in the farm land and need not be the best sites for groundwater. On the other hand, every farmer prefers to have own well irrespective of the number of similar wells in the nearby or adjacent farm land. However, a farmer who own a land practices construction of wells provided that, if there is no limitation of labor. In the area, the range of spacing of wells varies from less than one meter to above 70 meters (Fig. 2B). The main cause for such close spacing of wells is related to land ownership. As a result, the beneficiaries face a challenge of overexploitation of water particularly during scarcity or drought period. Consequently, some of the users are forced to limit their production frequency to the supplementary irrigation practices.

5.2.2.2. Wall Sliding

The shape of the hand dug wells is another problem encountered in the area. Majority of the wells in the area are trapezoidal in shape. The lithological logs of most of the wells indicate presence of loose materials in the upper layer, which ranges in thickness from 30 cm to 2.5 m. The loose soil being very fragile facilitates sliding of the walls of the wells.

To overcome this challenge, the farmers tried to cast with riprap by avoiding the black cotton soil. Even, under this circumstance, the over sliding occurs during high rainfall period. This has an impact both on the quality of the groundwater and on the function of the hand dug wells. As it was observed during inventory of hand dug wells in the rainy season, few of the wells were showing high turbidity caused by sliding of the wall.

5.2.2.3. Wastage of Lands

In Hayelom watershed almost 8% of the hand dug well beneficiaries have more than one well within a plot of land of 0.5 ha. Due to this, cultivated lands become out of production. A household who owned a hand dug well lose at least 28 to 154 square meter farm plots due to construction of the well. Households who have two well, the loss become double. Besides construction, the excavated soil and rocks, which are found dumped just near to the well, also occupied certain amount of the farmland and further minimizing the cultivable land. Based on the response of the interviewed beneficiaries, the cultivated land that became out of function due to accumulation of the excavated soils and rocks is 514.5 m^2 with an average of 22.37 ± 17.67 m^2 per hand dug well. Considering the total hand dug wells in the watershed, estimated total wastage of farmlands is about 9 - 12 ha.

5.2.2.4. Maintenance of Water Lifting Technology

Water lifting technologies utilization is considered as an advantage to boost food security in the area. However, skill of maintenance and spare part provision is seen as a main challenge in the area. According to the response of the beneficiaries, maintenance and checking of the non-functional pumps is a serious problem as the technical support is available only in the towns which are bit away from the watershed.

5.2.2.5. Market

In Hayelom watershed, the beneficiaries of hand dug wells produce different vegetables mainly for sale and part for household consumption. The dominant type of vegetable crops produced for market is onion, followed by green pepper and tomato. Farmers only have a chance to sell their product in the local market or in nearby town like Hawzien. Their product is transported by human or equines. By traveling almost 10 km, they sell their products at a price ranging from $ 0.05 - 0.40 per kilogram. This, according to the Bureau of Agriculture and Natural Resources (Hawzien Woreda) and the respondents, varies from season to season. Further, the irrigation practices also add to this problem. That is the majority of farmers are not market oriented instead produce the same type of vegetable, dominantly onion, at the same time. As a result, they face market problems. According to Mintesinot et al. (2004), creating better market access to the product crops especially for the perishable and high value crop might make the farmers to cultivate more crops and increase their income.

5.2.2.6. Water Scarcity

Next to market, water scarcity is considered as a main limitation in the watershed. Especially during non-monsoon season with low amount of rainfall, the amount of water recharge becomes low. As a result, the potential of wells providing water for irrigation purpose becomes limited particularly during February to mid of May according to the respondents. Besides, the community is also less aware on ways of water utilization and management.

In addition, other issues like produce storage limitations, lack of seeds for high value crops, pests and diseases of crops and vegetables also need attention to make irrigation a successful activity.

6. CONCLUSIONS

Geochemical data of majority of the groundwater samples in Hayelom watershed suggest that groundwater is suitable for irrigation purpose. Similarly, the soil data indicate that the soils are normal soils and free from soil salinity and sodicity hazards. However, as indicated by one sample some precaution needs to be taken while using groundwater from some of the wells in the area.

Even though, there are opportunities and constraints in the utilization of groundwater for irrigation purpose, considering the benefits earned by the farmers from this intervention, the advantages outweigh the disadvantages. Intervention undoubtedly has benefited the households to produce different high value crops and two to three times in a year. These improve the households feeding habit and also help to earn additional income through out the year.

To overcome some of the constraints and maximize the benefits of the intervention following suggestions are provided on the basis of the field and laboratory data.

- Detailed groundwater potential of the watershed needs to be investigated and community based wells may be constructed for proper utilization of groundwater and to overcome wastage of groundwater as well as cultivated lands.
- Farmers need proper advice on site selection, drilling and thickness of the construction of stone or masonry lining of the wall of the wells.
- Community based training is required to appreciate the water resources management policy of the country to avoid future conflicts on groundwater utilization, to enhance the recharging measures, for proper maintenance of water lifting technologies, and to help follow market oriented agricultural production.
- Information on possible market outlets should be provided by the responsible bodies.
- With the expansion of moisture harvesting structures and irrigation in the watershed, health related issues may increase in future which should get serious attention.

7. ACKNOWLEDGMENT

We are grateful to Mr. Mebrhatoum G/Kirstos**,** Associate Dean of the Graduate and Research Program of the previous Faculty of Science and Technology, Mekelle University, for his support through out the project periods. The Ethiopian Science and Technology Commission is duly acknowledged for funding this research project.

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