TIGRAY LIVELIHOOD PAPERS No. 5

Household water harvesting structures in Geba catchment

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September 2007

VLIR – Mekelle University IUC Programme

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Citation:
Fekadu Wondumagegnehu, Alemtsehay Tsegay, Dereje Ashebir, Hailemariam Tekie, Addisu Gebre, Mewael Kiros, Geerts, S., Raes, D., Nyssen, J., Deckers, J., 2007. Household water harvesting structures in Geba catchment. Tigray Livelihood Papers No. 5, VLIR – Mekelle University IUC Programme, 28 p

1 Introduction

The Geba catchment, located in the eastern, southern and central zones of Tigray (Northern Ethiopia), covers about 5180 km^2 and has a semi-arid climatic condition with erratic and torrential rainfall that often lasts for 2- 3 months, end June to beginning of September. The short rainy season coupled with high rainfall variability between seasons has exposed the catchment to recurrent drought. In addition, the small land size that rarely exceeds 0.5 ha per family has aggravated the problem of food security as the yield obtained from small plot size is hardly sufficient for a family until the next harvest (Fredu et al., 2006). Though it is possible to alleviate the problem of food security by having more than one harvest per year from the same field, the absence of irrigation water has made this difficult in practice.

In an effort to address the problems of recurrent droughts and to make water available for crop production during the extended dry period, due attention has been given to various water harvesting programs such as micro-dams, river diversion, ponds and hand dug shallow wells. In the beginning, about 20 years ago, a small earth dam-based irrigation has been initiated, but they were few in number. In the past 10 years, however, more attention has been given to these micro-dams based irrigation and an institute, SAERT (Sustainable Agriculture and Environmental Rehabilitation in Tigray), was established to undertake the construction of earth dams with the active participation of the communities. Accordingly about 60 micro-dams with a water holding capacity ranging from 50,000 to 4,000,000 m3 have been built in the region and a significant number of them are found in the Geba catchment (Nigussie et al., 2006; Tsehaye et al., 2007). SAERT, however, did not exist for long.

Following the dissolution of the institute, SAERT, a new strategy of water harvesting has come in place. This new strategy, unlike the previous one that gave top priority to water harvesting at community level, gives due emphasis on water harvesting at household level and in the past three years the construction of ponds and water wells has been carried out at household level to provide water for irrigation and domestic use. In the first year 2003 alone, about 30,000 ponds each with a design water holding capacity of 182 to 247 m3 have been built in the region (BOANR, 2004). A similar amount of ponds has been built in the second year and in general over 200,000 ponds have been planned over the next couple of years in the more drought prone areas of Tigray (BoWRD and REST, 2003). Though the exact numbers are not known, thousands of ponds have been dug in the Geba catchment. Similarly many hand dug shallow wells have been made and their number is increasing in the valley bottoms and in places with shallow water tables.

The water harvesting structures, particularly the ponds, have been built with the intention of providing supplementary irrigation for the main season crops after the main season rain ceases, - which often occurs by the time crops are in flowering. The main purpose of the hand dug shallow wells however is to grow vegetables like tomatoes, onion, cabbage etc. and to allow for crop cultivation twice or more in a year.

These water harvesting schemes are expected to bring a change on household welfare in terms of improving nutrition both in quality and quantity in the short run and in the long run it is considered as way out from extreme poverty through investment on farm land from the income generated by the water harvesting program.

2 Background of water harvesting

The Tigray region is divided into 6 administrative zones and 34 Woredas and it covers a total area of 53,600 km². In the region 621,000 households or 75 % of the total population of four million is food insecure and seriously threatened by droughts occurring every 3 to 4 years (Rami, 2003). TDPPB (2002) data from 1995 to 2001 show that on average there were nearly 1 million people who needed food assistance. This condition is not different for the people living in the Geba catchment either. Many of the Woredas in the catchment are severely affected by drought and food insecurity. The reported grain yield in the farming sector of the catchment is ranging from 0.4 to 1.8 tons per hectare. Many factors like management practices, crop type, variety choice, occurrence of disease and pests and low soil fertility can among others be listed as factors that are causing lower yields, but the central one is low soil moisture and the problems associated with it.

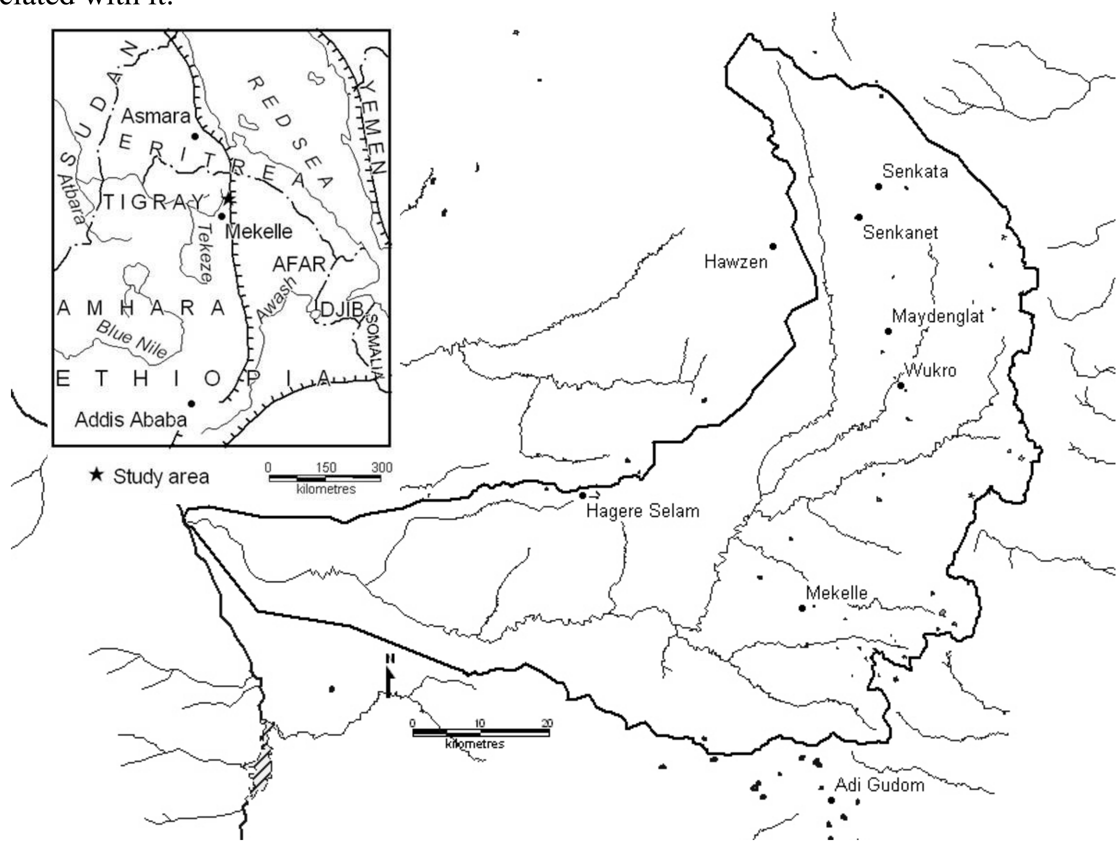


Fig. 1. Geba catchment with indication of the study sites and other locations mentioned.

Long term rainfall data of each site were analyzed from the locally collected meteorology data. The average rainfall of Wukro, Adi Gudom, Senkata and Hagere Selam, some of the Woreda towns in the catchment, is respectively 778 (±311), 511 (±220), 847 (± 475) and 719 (± 139) mm (Fig. 2). In all sites, the months of July and August together receive from 54 to 71 % of the total annual rainfall while the range for that of June and September is from 16 to 24 % (Table 1). In July and August the average rainfall per day is 7 mm with a recorded maximum of 80 mm. When the average rainfall is considered, it seems enough to grow many of the crops without moisture stress. However, the high standard deviation and the rainfall distribution indicate the erratic nature and the often low total of the rainfall.

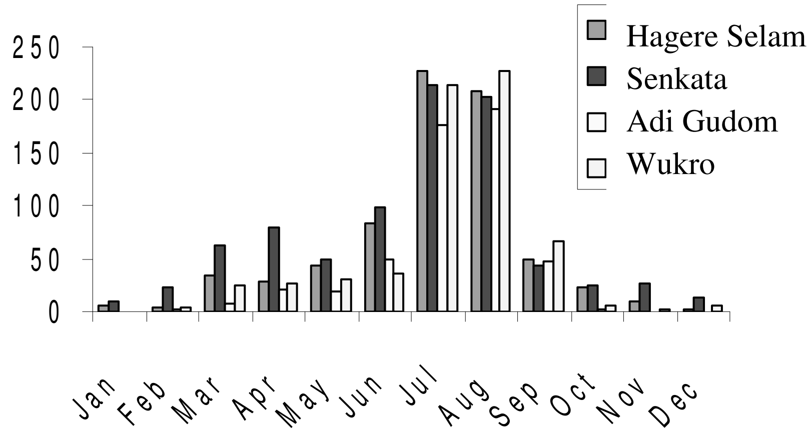


Fig. 2. Monthly rainfall distribution for the project Woredas

In addition to uneven distribution of the rainfall within the rainy season, the time when the rain starts and ends varies from year to year. This has generated variation in the length of the crop growing period during which soil moisture is not limiting. This period ranges from 37 to 70 days for the catchment. This seasonal rainfall variability is one of the reasons for year to year yield fluctuation as it often exposes the crop for a terminal stress in case of early cessation of the rainy season. Severe crop yield reduction in the project areas also often coincides with water stress that has occurred earlier in the reproductive phase. For instance, the short rainy season in 2003 increased the number of people who were food insecure to 2.1 million in the region (WFP, 2004).

Table 1. Monthly rainfall (% of total amount)

Woreda	May	June	July	August	September	October
Wukro	3.6	6.0	28.9	34.5	5.7	0.4
Hagere Selam	6.2	11.7	31.5	29.0	6.8	3.2
Senkata	5.7	11.7	25.2	24.0	5.2	3.0
Adi Gudom	3.2	3.7	31.0	48.4	6.7	1.2

Continuous moisture stress in the region, particularly over the last twenty years, has directly resulted in severe food shortages and decline in overall food production (Picture 1). It has also affected seed stocks and decimated livestock herds while forcing hundreds of thousands of people to migrate.

The high amount of rainfall during the months July and August on the other hand, produces runoff that leads to soil degradation. As a result thin and infertile soils are common for most crop land in the project areas except that of the valley bottoms where the soil is relatively thick and fertile. The generally low soil fertility in the catchment is a limiting factor for good yield, especially when rainfall distribution is favourable during a certain season. Nana-Sinkam (1995) indicated the magnitude of the problem by reporting that about half of the country's highland area is significantly eroded resulting in yield reductions of 2 to 3 % per year. This has put farmers and agricultural experts in dilemma whether to use chemical fertilizers, mainly N and P, to increase crop yield. The extension package initiated by the government proved that fertilizer and improved seed alone are not a guarantee for better yields. It was found that in the cropping seasons with unfavourable rainfall, the use of chemical fertilizer was not economically efficient and many farmers were in trouble to pay the loan they had taken to buy fertilizer. In fear of rainfall uncertainty many farmers have chosen not to apply fertilizers even if they know they loose extra yield that could be obtained by fertilizer application when the rainfall season is favourable. It is really difficult for resource poor farmers to decide on fertilizer application unless the risk associated with the rainfall is significantly reduced.

Picture 1. Aborted wheat crop due to low soil moisture at Adi Gudom

The negative effect of the high rainfall amounts in July and August is not only soil degradation but also excess water (water logging). Water logging in the main rainy season in both red and black soils has a compound effect on crop yield, Excess moisture in the root zone brings crop growth to halt and growth is resumed when the crop is relieved from water logging. Those crops are afterwards more drought prone than crops grown under well drained conditions. Severe yield loss can also occur due to nutrient leaching and diseases caused by the suitable conditions created by water logging.

The yield loss due to problems associated with rainfall caused farmers to adopt cropping systems that mitigate these risks. Crop mixture including cereal with cereal, crop diversification, and crop rotation are some. Barley, teff wheat, grass pea, are the dominant rain-fed crops in the highland as well as in the project Woredas and are sown either as sole crop or in mixture in the main rainy season.

The problem associated with the rainfall has been worsened by a decrease in land holding by individual farmers. In the past there was room for individual farmers to bring more land under cultivation as there was plenty uncultivated land, even if the arable land of Tigray is estimated to less than 20% of the total area 80,000 km^2 (Cowater, 2003). However, as time went by all the arable land came under cultivation and left no room for horizontal expansion. And the land holding by some small peasants reduced to the extent of 0.25 ha in the highlands, although 1 to 3 ha is common in the lowlands. This limited land holding coupled with traditional ways of farming practices made it difficult for the farming communities to be self sufficient in food production This inadequate cultivable land caused farmers: (a) to cultivate increasingly marginal land, (b) to either abandon traditional practices like fallowing or to reduce the fallow period to the level that it is no longer sufficient to allow soil fertility to be restored, and (c) to use more animal manures for fuel in substitute of fuel wood, as more of wood lands were cleared for crop production.

The EEA (2002) study indicated that declining farm size and rain fed farming practices are the major factors for the poor performance of the agricultural sector. The study revealed that 75 percent of sample farmers in Tigray own holdings less than the minimum area required for minimum food production. For example, in some of the project Woredas a farmer is classified as rich if he/she produces food that lasts for not more than 10 months, indicating the magnitude of the problems resulting from the decline in landholdings per capita.

All these problems call a lasting solution that can make farmers self sufficient in food production. It is clear that water shortage is the central problem that should be solved in order to solve all the other problems associated with it. In the rainy months there is more water available than can infiltrate or be used by vegetation. This excess water could be harnessed for crop and livestock production and domestic use later.

The issue of water harvesting has been brought on board since the famous famine of the year 1984 with the aim of mitigating droughts that occur frequently. Initially it was micro-dams and river diversions got utmost attention. The presence of these micro-dams and river diversions allows vegetable production of lettuce, cabbage, carrots, tomatoes, pepper, potatoes, onion, garlic, red beet, sugar beet, green maize, and spices like cumin. However, the production was limited to sites where there are micro-dams and river diversions, and it has been understood that it is difficult to construct micro-dams although the initial ambitious plan of the government was 500 micro-dams in 10 years. Considering the difficulty of addressing the problem of food shortage through constructing micro-dams and diversions only, other techniques of water harvesting like ponds and hand dug wells, of which many of the households can benefit, have been constructed. This new water harvesting program focusing on individual household has given utmost attention to meet the objective of insuring food security at household level since the 2003 fiscal year.

3 Water harvesting structures and their characteristics

3.1 Shallow wells

3.1.1 Location

All the shallow wells (Picture 2) are located at places with shallow water tables, mostly at the valley bottom, and are excavated by hand shovel below the water table level of the dry season. Hundreds of hand dug wells have been excavated in the project area and their number is expected to increase in the coming few years as they are seen as an escape from poverty by many farmers.

3.1.2 Structure

Hand dug wells were designed with a size of 4 m by 4 m at the mouth with varying depth depending on the water level and geographical position. The observed size, however, varies considerably due to the differences in shape (circular, rectangular or square), depth, width, slope of the side walls (see Picture 3). Most of them are rectangular or circular with a diameter ranging from 2 to 8 m at the mouth. The variations in depth between different hand dug wells are primarily due to their location in the valley or on the plateau and due to the water yielding ability of the rocks. Those wells located at higher elevation are relatively deeper than those located at a lower point and those wells with a relatively high water yielding ability are relatively shallower than the low yielding ones.

Picture 2. Shallow wells sites at Maydenglat

In addition to the location and water yielding ability, farmers' perceptions on water levels of wells are another factor causing the differences. There are differences in farmers' perception about the changes in the water table as the dry season progresses. Those who assumed the water table remains constant throughout out the year stopped digging soon they got water, while others kept on digging deep, some up to 8 m depth, to make it a reliable water source throughout the dry season. In some cases when the incoming water exceeded the digger's bailing rate farmers are compelled to stop digging which can be the cause for the differences in well depth.

Picture 3. Structural view of hand dug shallow wells

Many well side walls are lined with stones to prevent them from collapsing. However, some of the wells with perpendicular masonry walls failed to withstand the water pressure during the rainy season and collapsed (Picture 4), particularly at places where the soil is deep. The collapse of the masonry wall made farmers to either invest extra time and money for a repair work or abandon it. Many of them have been abandoned after their wall collapsed due to lack of labour or money. Wells abandoned and repaired in two sites are presented in Table 2.

Picture 4. Wells with collapsed side walls

Table 2. Number of wells abandoned and repaired after the masonry walls collapsed

Site	Number of wells observed	Wells with collapsed masonry wall	Abandoned after wall collapse	Repaired after wall collapse	New well dug
Maydenglat	27	12	10	2	2
Senkanet	20	7	3	4	1

3.1.3 Capacity and water yield

Samples of well length and width at the mouth and base or the diameter at the mouth and base together with the well depth were measured and the total water amount in the wells at the end of the rainy season and in the middle of the dry season was estimated. As it is shown in Table 3, the water holding capacities of wells differ significantly due to the differences in size (R^2 = 0.87) and the productivity of the wells. The productivity of the wells was estimated by measuring the volume of water stored for day(s) (1 to 5 days) after all the water from the well was pumped out and by questioning farmers on the number of hours required for the water to reach the measured water level before the last irrigation.

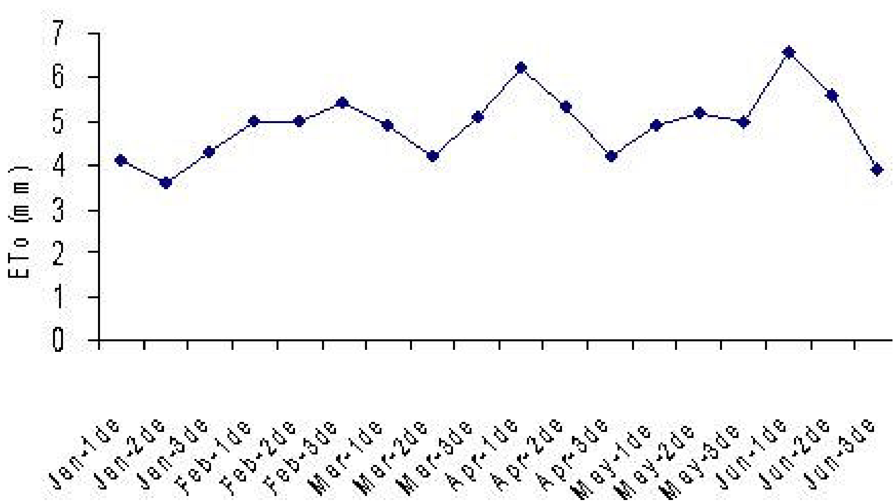


Fig. 3. ETo for each decade of the months that irrigation is practiced

Soon after the cessation of rainfall all wells remain filled to the mouth as the water yield of wells is high and the need for irrigation is nil. However, as the dry season progressed, the water table decreased and the level of water diminished in all wells and it reduced more as the dry season progressed. This resulted in water yield variation between wells. The sampled wells' water yield varied from 1 to 27 m³/day. The differences might have been due to lithology, geologic structure, and topography differences. One of the most important factors in providing a high well yield is the lithology of the aquifer (Royer, 1983) Saturated sand and gravel yields a lot of water; fine sand or silt formations yield water more slowly.

Table 3. Water holding capacities and water yield of wells

Well	Water holding capacity at the end of the rainy season (m³)	Water yield at the end of the rainy season (September) (m³/day)	Water yield in the middle of the dry season (march) (m³/day)	Land under irrigated cultivation (ha)
1	68.0	48.0	16.0	0.10
2	41.8	25.3	8.4	0.25
3	21.8	3.6	1.0	0.04
4	95.7	66.0	13.2	0.18
5	132.0	95.0	27.0	0.18
6	68.0	16.0	4.0	0.10
7	74.8	55.6	5.5	0.20
8	51.8	18.2	6.5	0.25
9	91.2	57.5	29.5	0.18
10	50.0	7.5	3.7	0.05
11	49.0	15.8	3.2	0.08

3.1.4 Irrigated land

The farmland brought under irrigation by individual farmers is ranging from 36 m^2 to 2500 m^2 (Table 3; Picture 5) and are independent of the productivity of the well. The rate of reference evapotranspiration of the sample area for the period that irrigation activities are taking place (January – June) is ranging from 3.6 to 6.6 mm and averaging 4.9 mm (Fig. 3). According to Doorenbos and Pruitt (1977) the Kc value for the initial, mid and late season stages of tomatoes, the crop that most cultivated under irrigation, is 0.6, 1.15 and 0.7, respectively. Thus, taking into consideration the crop Kc and the peak and the average reference evapotranspiration of the site during the crop growth period, the average and peak daily water requirement of the crop is 4.3 and 7.1 mm. If the water yield of the wells had been taken into consideration to decide the size of the land that had been brought under cultivation it would have been quite different from that of the current cultivable land (Table 3). Nearly half of the sampled farmers brought more land under cultivation than what should have been brought if the water yield of the well had been considered. It is vividly seen that many of their crop is grown under water stress conditions, and a relatively lower yield is expected from their field. There are also farmers who failed to fully exploit their well water, though only few (Fig. 4).

Picture 5. Fields of farmers at Senkanet and Maydenglat where water is applied

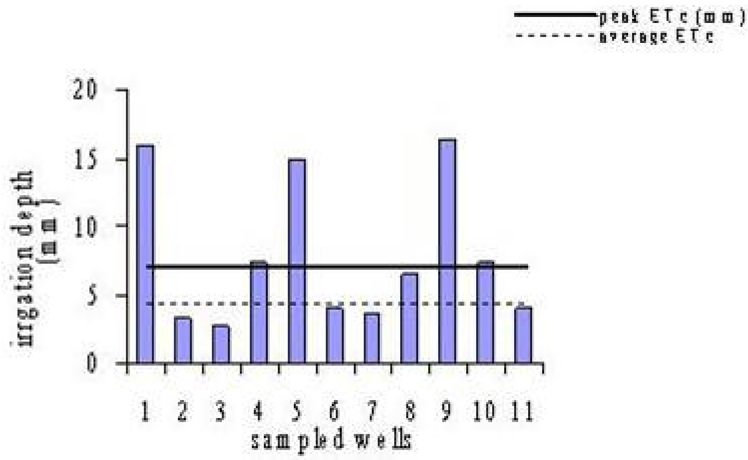


Fig. 4. Calculated daily irrigation depth when the entire daily water yield is assumed to be used for irrigation

3.1.5 Irrigation scheduling

Soil samples of different farmers growing onion (Fig. 5a) tomatoes (Fig. 5a) potatoes (Fig. 5b) and maize (Fig. 5c and d) were taken randomly and the soil moisture content was determined gravimetrically and by means of TDR. At each sampling time 5 replications were taken from each farmer's field. Similarly the bulk density was determined from undisturbed core soil samples taken from one farmer field as the soils of all farmers are approximately the same. The moisture content at field capacity (pF = 2.0) and wilting point (pF = 4.5) was determined in the Mekelle University soil physics lab. The total available water was computed and the readily available water was set to 45 % of the available water for maize, tomatoes, onion and 30 % for potatoes. The effective root depth for maize and the other crops was estimated around 1 m and 0.4 m respectively. The results show that the soil moisture contents in the fields of potatoes and onion were well below the allowable deficit, at least, during the crop growth period when the samples were taken. Though the samples that were taken hardly represent the soil water conditions of the whole crop growth period, it can be generalized from the limited samples taken that the crops were grown under water limited condition at least in some of their growth period. The sampled farmers who grew maize and tomatoes kept the soil water level between field capacity and the minimum allowable deficit indicating that water might have not been limiting for the crop, though frequent sampling had not been taken (Fig. 5). Thus, the timing of irrigation is not always determined according to a maximum allowable soil water deficit, but rather it is determined according to the available time of farmers for watering, the availability of water and to individual farmers feeling. Water, a limiting factor for the main season crops, seems a factor that reduces yield even under irrigated conditions, though the degree of limitation varies.

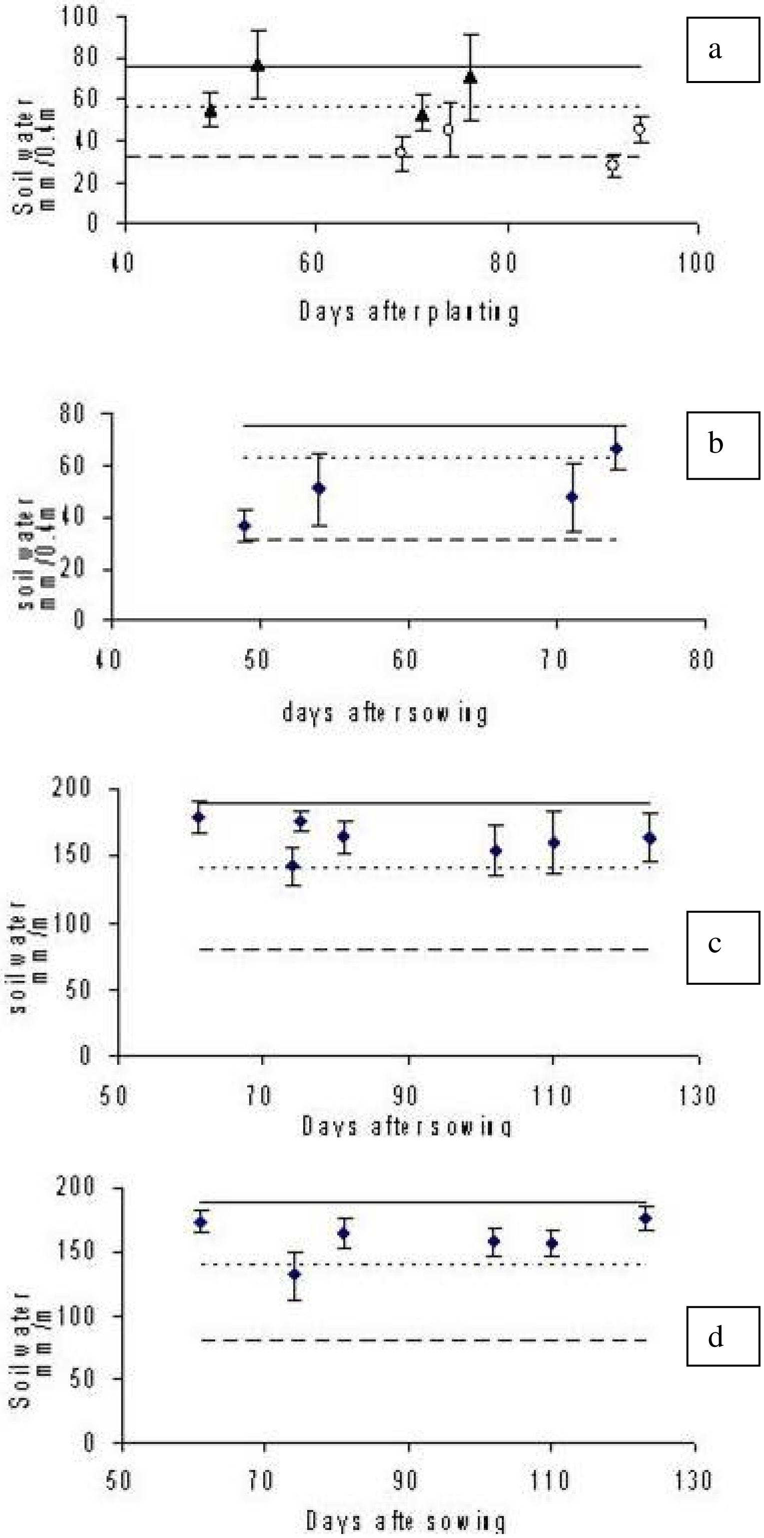


Fig. 5. Soil moisture content (a) for onion (○) and tomatoes (▲), (b) potatoes and (c and d) maize for farmers field a and b, respectively. The lines represent field capacity (▬), allowable deficit (·····) and wilting point (---)

3.1.6 Field application

The water distribution of each farmer's field was indirectly assessed by calculating the standard deviation of the five replications taken at each sampling time. The standard deviation for onion, potatoes and tomatoes varies from 6 to 13, 7 to 14 and 8 to 20 mm, respectively. Similarly the standard deviation for maize field 'a' and 'b' was 8 to 24 and 8 to 28 mm, respectively. The soil moisture content at time when samples were taken revealed the uneven distribution of water in the field. The soil moisture was above field capacity in some parts of the field while it was below the allowable deficit in other parts of the field. In addition, the high standard deviation between replications shows the difficulty of maintaining uniform water application, which results from improper levelling of land and furrows and from the differences in the rate of application to each furrow. Even in frequently irrigated fields with moisture content between the allowable limit, there are individual or groups of plants whose yield is limited due to water shortage.

3.1.7 Water use efficiency

The current practice of water application has many drawbacks, one of which is the method of irrigation that varies. Farmers are using flood, furrow and basin irrigation depending on the types of crops they are irrigating. These irrigation methods differ in performance. For instance Yavuz (1993) tested the application efficiencies of sprinkler and open end furrows and he found that sprinkler irrigation and open end furrows had the application efficiencies of 92 % and 67%, respectively. Similar studies by Çetin (1997) revealed that the water use efficiency for furrow irrigation is low as compared to drip and sprinkler irrigation. When field application efficiencies of the irrigation methods practiced in the project area are considered, they may not exceed 35 % indicating there is substantial loss of water, which would otherwise remain unexploited or would be used for irrigating more land.

Picture 6. Basin and flood irrigation of respectively onion and barley

The second cause for low water use efficiency is the ratio of evaporation to transpiration. In the season when irrigation is practiced, the potential evapotranspiration ranged from 3.6 to 6.6 mm/day. In most of the growing period the possible leaf area index of the major irrigated crops (onion, cabbage and tomato) in the catchment is less than 2 indicating that evaporation by far exceeds transpiration. This shows that there is a possibility of reducing water that is lost directly from the soil and make it available for crop use.

A third important efficiency consideration results from the application rate. The application rate depends on the amount of water stored in the wells and on the kind of pumps used to extract water. Those farmers who own or rent pumps exploit all the available water in the well without giving any consideration to the required irrigation depth. And this may hasten the depletion rate of the ground water. All these items call for efficient utilization of the available water to ensure the sustainability of the water harvesting program.

3.1.8 Water withdrawal

A treadle pump is used by most farmers to extract and direct the water to the channels. Though they are not widely used, motor driven pumps are also in use. There are farmers who bought motor driven pumps for renting it on hourly bases or to use it for renting a land from farmers who own a well with the agreement that they will divide the harvest equally. Only few farmers are using buckets to extract water. The presence of more treadle pumps and motor driven pumps is an indication that the water harvesting program is paying-off and has a widespread acceptance. Almost all farmers are practicing furrow and basin irrigation.

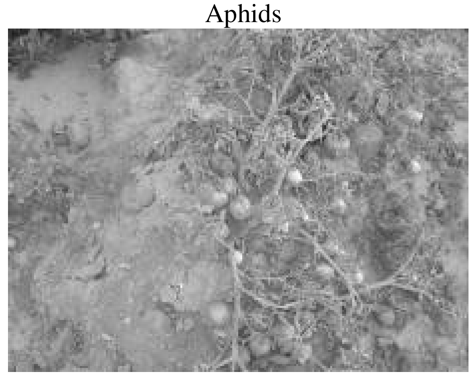
3.1.9 Water quality

So far no direct or collateral salinity damage was observed. The average ECw and sodium absorption ratio (NCR) of 11 hand dug wells from Wukro sites were in the range of 210 to 500 µS/cm and 0.419 to 2.485, respectively (Mulatu Tumoro and Atsbaha, 2004). The standard EC values of irrigation water that have no effect on soil salinity and permeability are 750 and 500 µS/cm, respectively (Doorenbos and Pruitt, 1977). Similarly irrigation water is free from toxicity when the adjusted SAR value is less than 0.5 (Doorenbos and Pruitt, 1977) so that the water is an excellent water for irrigation.

Head rot

Aphids

Frost damage



Leafs eaten by larvae exposed the fruit to sunburst

Picture 7. Vegetable crops affected by diseases, insect pests and frost damage

3.1.10 Crop management

The experience of farmers in vegetable production is low, and producing vegetables at a relatively large scale using irrigation water is a recent phenomenon. Therefore it is not unexpected to see poor management of irrigated crops. Most farmers may know the basic of crop management but they lack perfection. Proper tillage practice, particularly land levelling, crop spacing and proper population density, timing and rate of fertilizer application, training in crops like tomatoes, selection of crops and varieties and crop protection are some of the lacking management aspects. They are the most important factors in defining yield as water is assumed not to be the most important limiting factor. Furthermore continuous vegetable production at a relatively large scale may create favourable conditions for the incidence of new diseases and insect pests, which may limit vegetable production. Farmers growing vegetables are currently evaluating the amount of money they earn from vegetable production. They may have not noticed the danger that diseases and insects pests pose on to their crops and therefore on to their livelihood. Signs have already been observed in the visited sites like yellow rust infestation of onions and black rot of cabbage in Wukro can be mentioned. The incidence of these diseases is expected to reduce the yield of some fields by half.

3.1.11 Impact

Beneficiaries expressed that the earning of individual farmers have greatly improved (Picture 8). It brought food security at household level and improved the living standard of farmers owning hand dug shallow wells. They have changed their feeding style both in terms of frequency and quality and managed to buy new dresses for them and their children. These in turn have brought a change in their health status. Diseases related to malnutrition declined.

In the past, a lot of children were kept away from school to look after the house when parents went out in search of jobs. The hand dug shallow wells, however, have given them the opportunity to generate their own income in their own farm near their backyard so that children have been relieved from keeping houses and extra money became available for buying school equipment. This brought an increase in student enrolment and a decrease in dropout. The Bureau of Education of the Wukro Woreda “Tabia Negash Maydenglat” claimed that in 2003 school dropout reduced from 8 to 5 % after the water harvesting program was introduced.

Picture 8. The advantage of hand dug wells: cabbage ready for market at Maydenglat

3.1.12 Sustainability

One of the major threats for the sustainability of the hand dug shallow wells is over utilization of the ground water. In some places, distance between two hand dug wells is not more than 10 m and many farmers like to have more than one well and some of them have already dug two wells in their farm land. The sole reason for this is the need to get more water in order to bring more land under cultivation and/or to irrigate their land more frequently. The other threat is the stability of the side walls. A repeated collapse of side walls made some farmers to completely abandon their wells.

The overexploitation problems can be easily reduced by taking measures that either increases the rate of recharge through catchment treatment or increase the water use efficiencies through taking agronomic measures or both. Ground water recharge relies on the area where water from precipitation is transmitted downward to an aquifer. How much water infiltrates depends on vegetation cover, slope, soil composition, depth to the water table and other factors. Recharge is promoted by natural vegetation cover, physical structures (terraces, bunds, percolation ponds, trenches etc.), permeable soils, etc. To increase the rate of recharge there is a need to embark on integrated catchment management. A lot of work has been done on this regard, particularly on the physical structures (Nyssen et al., 2006). However, as the catchment has a generally low vegetation cover and is highly degraded more catchment rehabilitation work is required.

Agronomic measures such as varying tillage practices and mulching can reduce the demand for irrigation water. Another option is deficit irrigation, with plants exposed to certain levels of water stress during either a particular growth period or throughout the whole growth season, with comparatively low reduction in yields.

The technical problems can be alleviated by training farmers or/and extension agents who are offering technical advice to farmers.

3.2 Ponds

3.2.1 Introduction

Extended dry periods and the absence of sufficient water for animal and human uses made some communities to embark on rain water harvesting long ago. The harvesting has been done by constructing earth community ponds with an average water holding capacity of 500 m^3 (Cowater, 2003). This implies that pond construction for rain water harvesting is not new in the region. What makes the currently introduced earth household ponds new is that they are constructed on a massive scale with the purpose of providing supplementary irrigation to the main season crops. In addition, the harvested water can be used for home gardening, human sanitation and drinking water for livestock.

The technology may have been preferred because it is simple to implement and requires low input with labour and materials available at local levels. The goal is to construct half a million ponds in five years (BOANR, 2004). In 2003 the region planned to construct 40000 ponds, but managed to accomplish 30,588. The plan for 2004 was massive, 160,000 ponds, but only 23,311 ponds were constructed till the end of July (BOANR, 2004). Though data on the number of ponds constructed till 2006 data are not available in the region or in the catchment, the pace of pond digging has been slowed down as farmers do not accept the water harvesting technology wholeheartedly.

3.2.2 Design

The size and capacity of the ponds vary, though the majority of ponds have a design size of 12m x 12m x 2.5m with a potential water holding capacity of 184 m³ (see appendix). The harvested water is designed for supplementary irrigation of 2000 m² of land after the cease of the rainfall. However, the actual water holding capacity of most ponds is below the designed potential (Table 4). There are many reasons for the observed differences such as lack of skilled man power, flaws in implementing the design of the structure, beneficiary's perception and problems of lining materials including substandard or punctured polyethylene materials (Picture 9).

Table 4. Actual water holding capacity of 22 ponds in percentage as compared to the design potential)

Average	Maximum	Minimum
76.8 ± 14.0	94.1	46.0

Picture 9. An overview of lined and rip-raped ponds

3.2.3 Site selection

The trained water technicians, extension agents and administrative bodies played a great role in site selection and in the identification of farmers who were and would be involved in the water harvesting program. To meet the objective of pond construction, many of the ponds are located in farmlands and few of them are near homesteads.

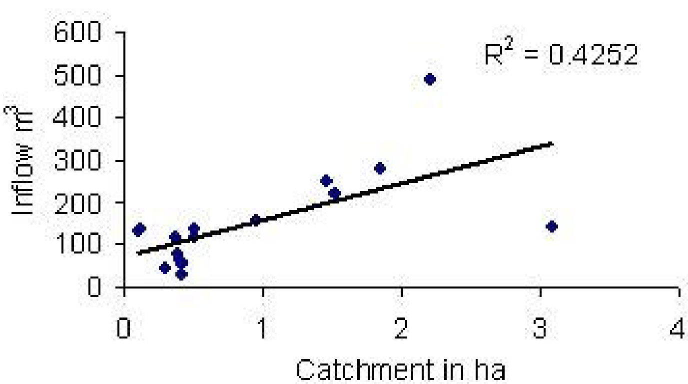


Fig. 6. Runoff and catchment area relationships estimated from 17 ponds

As it is a new experience the selection of sites is far from perfect, particularly in considering the size of the catchment. The size of the catchment that allows producing sufficient runoff to fill the pond was not considered in most of the visited sites. As it is shown in Fig. 6, there is a linear relationship between catchment areas and estimated runoff produced by the catchment areas of 17 ponds. The relationship, however, is not strong indicating that it is not only the size of the catchment that determines the volume of runoff, but also factors like the characteristics of rainfall (intensity, duration, and distribution), catchment characteristics (shape, drainage density, and topography), soil characteristics (infiltration capacity, permeability, texture and depth), land use and vegetation cover. As a consequence catchments of different sizes can produce the same amount of runoff and vice versa (Fig. 6).

3.2.4 Lining material

The prevailing lining material of the observed ponds is a plastic sheet made of black polyethylene membrane. The unit cost of the polyethylene membrane is 1500 Birr, but has been sold to farmers on credit bases with a subsidized price of 650 Birr. It has a good water retention capacity and nearly 80 % of the observed plastic lined ponds around homestead contained small amount of water in the middle of December 2004, 3 months after the cease of the rainfall (Fig. 7). Most of the beneficiaries covered the polyethylene membrane with stone layer. Many of them complained that the lining material they received had a defect so that their ponds couldn't contain water to their full capacity. Beneficiaries who received substandard (not properly welded at the joint) and punctured plastic liner (upon loading and unloading) complained that the vegetable crops that they have planted suffered with moisture stress as their ponds couldn't retain enough water (Picture 10).

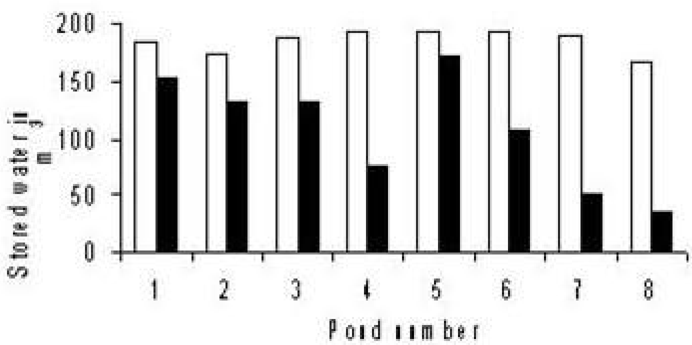


Fig. 7. Actual water holding capacity (□) and water level of ponds (■) when the rainfall was ceased

Picture 10. Soil water shortage in onion and swisschard crops grown near ponds

The other method of lining is with cement plastering. Cement lining costs 1300 Birr per unit, but farmers obtained it on credit bases at a price of 390 Birr. All observed ponds lined with cement had no water when they were visited. Cracks through which water leaked were noticed in nearly all ponds (Table 5). What seems to be a cheap lining method, at least for a time being, can be more expensive when the repairing costs are considered.

Table 5. Seepage and evaporation losses (m^3/day) of 28 measured ponds lined with different materials

Average		Maximum		Minimum	
Seepage	Evaporation	Seepage	Evaporation	Seepage	Evaporation
9.10 ± 4.82	0.13 ± 0.05	19.81	0.26	0	0.07

The cheapest but inefficient lining material is clay. None of the clay-lined ponds that were observed contained any water. In almost all clay-lined ponds the harvested water was lost nearly in a week period after the cessation of rainfall while ponds lined with black polyethylene membrane retained more water (Fig. 8 and 9) unless there was a puncture near the base of the pond. The soil types used for lining and the compacting process are some of the factors that were mentioned as possible failure causes.

Measured seepage loses in 28 ponds (Table 5) are a good indicator for the differences of the lining materials and the danger that seepage losses pose on the sustainability of the scheme. Considering the seepage and evaporation loss BRL and BCEOM (2004) also made a conclusion that it is not efficient to implement ponds less than 3.5 to 4m deep.

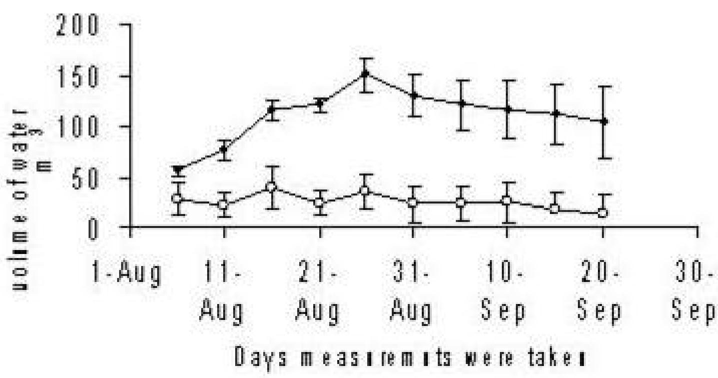


Fig. 8. Average volume of water in the lined (black dots) and unlined (white dots) ponds at different time during the rainy season

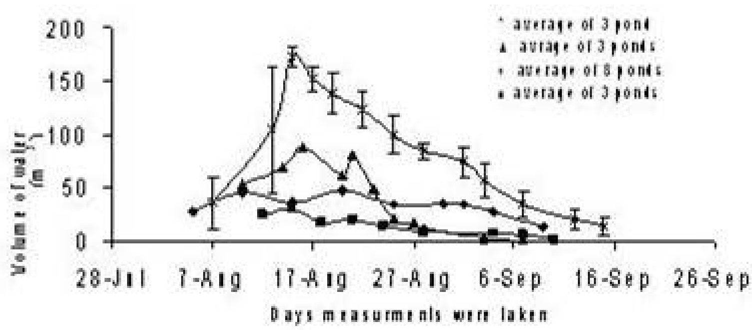


Fig. 9. Volume of water in the unlined ponds at different time during the rainy season

3.2.5 Silt trap

Many of the ponds had little sediment that could easily be removed by farmers and siltation was not seen as a serious problem by many farmers. Some of the dried ponds had a sediment load of nearly 10 cm thick. Nearly all observed ponds have a silt trap (Picture 11), but none of them met the designed dimension, 2.5 x 2.5 and 1.5 m depth. However, the efficiency of these silt traps was measured in nearly 30 ponds and it was found that they reduced sedimentation on average by more than 60% (Table 6).

Table 6. Silt content of the runoff before and after the silt trap and silt trap efficiency

	Silt content (g/l)		Difference	Efficiency in %
	Before	After		
Average	2.37	1.48	0.87	62
S.D.	0.88	0.70	0.52	80
Maximum	3.82	3.33	2.07	87
Minimum	0.80	0.37	0.06	46

Picture 11. Silt trap structure and silt deposit in pond

3.2.6 Water extraction

The treadle and the motor driven pumps that are in use for taking out water from shallow wells are not in use to extract water from ponds. Almost all farmers are using buckets to lift water. This mechanism is not only inefficient, but it also increases the risk of drowning as the plastic lined ponds without stone riprap are very slippery. Many of the ponds with a riprap have stone steps for going in and out of the ponds. Some of the farmers owned ponds without riprap, but lined with plastic and tie their chest or shoulder with a rope on a living tree when they are lifting water or they take other extra caution.

3.2.7 Pond management

Farmers have to believe in the construction of ponds in order to perform all the maintenance work required afterwards. If a pond is only installed to get paid for it then the owner will not be much interested to take care of his or her pond afterwards.

Many farmers have their own reservation with regard to the importance of ponds for supplementary irrigation. Consequently, many of them require a push to line their ponds with plastic or concrete liner, to repair damaged ponds and runoff channels, to fence them in order to protect animals from going in, to remove silt stored in their pond and to invest in water extraction equipments like a treadle pump. It is, therefore, unlikely to expect good management of ponds. Some of the ponds have already been abandoned and are no more in use for water harvesting (Table 7).

Table 7. Conditions of visited ponds one and half months after the cessation of rainfall (2005)

Woreda	Number of visited ponds	Abandoned ponds	Lined with plastic	Ponds with riprap	Water	Average Land irrigated (m^2)
Hagere Selam	14	8	6	4	2(very little)	5
Senkanet	5	0	5	4	No water	10
Adi Gudom	7	1	6	6	5	120
Hawzen	4	1	3	0	*	

* The ponds in Hawzen are used for storing diverted river water

3.2.8 Impact

Ponds constructed at the homestead have a better performance than ponds located in farm land. For example 20 plastic-lined ponds visited at and Wukro Woreda and Adi Gudom in 2004 had water 3 months after the cessation of rainfall, but none of the ponds located in farm land had water. The water in the ponds was used for irrigating small gardens with cabbage, peppers, tomatoes, and root crops planted after the end of the rainy season. In addition, some farmers were using it to irrigate freshly planted geisho (Rhamnus prinoides), fruit (orange, avocado, mango, lemon, citron) and coffee trees at homestead.

The land covered by different types of irrigated vegetation ranges from 5 to 220 m^2 depending whether the harvested water is used for supplementary or full irrigation. The figure is far below the designed potential irrigable land from the harvested water. Those farmers who were planting crops like onion during the rainy season and brought them to harvest using the pond water for supplementary irrigation managed to have large size of land and they are the one who appreciated the water harvesting scheme. Those who solely depend on harvested water for raising vegetable crops had plots as low as 5 m^2 ha.

On the other hand nearly all ponds constructed in the farm land for supplementary irrigation failed to meet their objective as many of them are out of function and neglected.

Overall the impact of ponds in changing the food security conditions, particularly of those made in farming land is negligible. The interest of farmers in maintaining the already existing ponds and digging new ones is dwindling as they see less benefit from it.

4 Conclusions and recommendations

The agricultural practices of the studied region are entangled with many problems, both of natural and human nature and of different magnitude. Unravelling these interwoven problems requires priority setting based on the magnitude of the problems. It may be easy to supply enough fertilizers, improved seeds and to exercise better management practices, but the required outcome which is an increase in yield, can’t be achieved if water is in short supply as it is now. This makes water the crucial growth factor that should be addressed first and foremost before attempting to solve the other problems that the agricultural sector faces. Therefore, any practice that helps to harness the water resources, both the underground and the rainfall, is a step forward to food self-sufficiency at household level.

However, the water harvesting program should be accepted by the end users who are in dire need of feeding their family throughout the year. It is then that making improvement on the structure, irrigation methods, and crop management practices is possible. In this regard shallow wells have impressed farmers and it may not be surprising to see many more shallow wells in a couple of years. However, to insure their sustainability and to avoid overexploitation the following mitigation measures have to be taken.

- Wall collapsing consumes a lot of labour for repairing, which could otherwise be used for other productive purposes. In addition farmers may loose interest on the long run when the masonry walls collapse again and again. This may requires training of foreman who can assist and guide farmers when shallow wells are dug.

- Overexploitation is a threat for the sustainability of the hand dug wells resulting from unbalanced discharge and recharge rate. It requires extensive assessment of the water potential of the perched aquifer to quantify the yearly extractable amount. This would allow proper planning and management of the program to ensure its sustainability.

- The infiltration rate determines the replenishment of the ground water and can be increased by treating the catchments with biological and physical means. Treating the catchments or repairing the physical structures requires the mobilization of not only the beneficiaries of the water harvesting scheme, but the whole community.

- The potential of ponds is far less than that of hand dug wells. This may be the reason why most farmers have a doubt on it. Its use, particularly for supplementary irrigation of the crops sown in the main rainy season, is questionable. However, it can be used for irrigating vegetable crops sown at the end of the main rainy season.

- Substandard and punctured lining materials dashed the hopes of some farmers who were enthusiastic to bring a change on their life using the water harvesting program. Checking the lining materials upon distributing for punctures and manufacturing errors would prevent extension workers or the implementers from being untrustworthy. On the other hand it would save more time, labour and money of farmers.

- It is not within the reach of individual farmers to replace the punctured and substandard black polyethylene membrane and it is not economically feasible either. However, there are farmers who lined their ponds with substandard and punctured plastic liner and there will be incidences of punctured or torn liner. The need for plastering services is crucial.

- A scarce resource harvested after investing time, money and labour should be used efficiently. The use of irrigation calendars, improving the methods of irrigation, the use of water saving techniques like family bucket drip irrigation, and mulching should be considered.

- Proper crop management practices including the use of optimum seeding rate or plants per unit of area and the use of organic or inorganic fertilizers and responsive varieties are imperative to reduce wastage of water through evaporation.

- Healthy plants can easily exploit the available resources and can have fast growth so integrated pest and disease management should be considered. Its benefit is not only to protect the plant and ensure the sustainability of vegetable production, but to improve the water use efficiency.

- The interest of farmers to have permanent crops like fruit trees is high and some are raising these crops with a hope that the water harvested by their pond lasts long. However, it should be noted that when they are grown their demand for water is high so that growers have to be sure of the presence of supplementary water other than the water stored in their ponds.

- Most ponds are not fenced and are accessible to kids and animals. Kids can drown in the ponds as the plastic liner is slippery. Animals can go easily into the pond and in the process the plastic liner can be damaged and seepage problem will follow. Fencing the water harvesting structures is essential.

- All improvements envisaged in efficient utilization of water through proper harvesting, better irrigation methods and crop management is only possible if the capacity of the extension workers and farmers is increased.

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