

# Characterization and Impact Assessment of Water Harvesting Techniques: A Case Study of Abreha Weatsbeha Watershed, Tigray, Ethiopia.

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## **Abstract**

*Agriculture is the dominant economic sector in Ethiopia on which 85% of the population in the country depends on agriculture for their livelihood. However, the agricultural sector in the country is highly threatened by land degradation, recurrent drought and associated water stress and low soil fertility status. To reverse this, water harvesting technologies have been given top priority particularly in the drought prone highlands of Tigray, Northern Ethiopia. Since 1990's, several techniques of in-situ and ex-situ water harvesting systems were implemented. Several studies have been carried out showing the success and failure stories of water harvesting intervention in Tigray. However, there are limited attempts to investigate the characterization, suitability of water harvesting systems and assess their ecological and socio economic impacts. This study is, therefore, aimed at characterization of water harvesting systems and assesses their impact on ecological restoration in Abreha Weatsbeha watershed. The water harvesting systems were characterized in terms of size, storage capacity, cost, site suitability and their impacts on yield, water availability, agricultural production and land rehabilitation. From the study area, around eight effective water harvesting techniques (WHT) were identified and characterized. Before the intervention (1984G.C.), the land use types in the watershed consist bare land (34%), cultivated land (32%) and bush land (32%) with only 2% of grazing lands. However, after treatments of the watershed have been undertaken for 12 years (1998-2010), the land use land cover has changed dramatically and new land uses such as exclosures and irrigation lands were introduced in hundreds of hectares. In these 12 years of intervention, the land use land cover change is tremendous. Bare lands have been drastically reduced to 2% while cultivated lands, bush lands, area closures, and irrigated lands increased up to 33%, 40%, 15%, and 8% respectively. However, the analysis shows that the grazing lands remained unchanged. The change in bare land is unbelievable in that it is almost lowered by 94.2%. The ground water level has increased from 15 m (1998GC) to 3m (2015GC) below ground surface and access of the community to safe domestic water has reached around 96%. The production from 619ha of cultivated land is significantly increasing every year and in 2014GC the annual production of the watershed was recorded around 81133.75 quintals of which 78% was from irrigation and the other 22% was from rainfed agriculture. The impact of the integrated watershed management has not been only increasing crop and horticultural production but also playing significant role in livestock and honeybee production. The total livestock production of the watershed reaches more than 8784 heads and 1490 Beehives. Generally, the innovation of the local community is admirable and the change is so boldly visible that the watershed is now becoming a model for watershed management. Finally, the saying in the community goes as "A man who has water has everything".*

**Key words:** water harvesting, characterization, land suitability, land use, land cover change, and ground water

## **1. Introduction**

The Ethiopian economy is mainly dependent on agriculture, from which about 85% of the population makes their livelihood. More than 70 million people depend on this sector directly or indirectly. In reverse, the pressure on land is increasing every time forcing farmers to use marginal lands for agriculture production. This leads to land degradation which becomes a crucial problem to the productivity of agricultural lands (FAO, 2003). The effect of land degradation is not only manifested in limiting the productivity of agricultural lands but also in reducing the availability of water in the soil (Hailu et al., 2012; Kifle et al., 2014; Tsegay et al., 2010). It impedes the infiltration of water and causes much of it to be lost as runoff. Coupled with land degradation, the low and highly variable rainfall in arid and semi-arid areas places major limitations on agricultural productivity(Barry et al., 2006; Bruins et al., 1986; Bulcock and Jewitt, 2013; Kifle, 2015; Ngigi, 2003; Seleshi et al., 2006). Even in years of good rainfall, a dry spell during critical periods of crop growth (i.e. the mid-season) often leads to widespread crop failure or significantly low yield. In addition to the unreliable and highly variable rainfall in the arid and semi-arid parts of the world, low soil fertility is another limiting factor for agricultural production. Ethiopia is one of those countries that are often adversely affected by poor rainfall and low soil fertility. Investments in improving water resources and soil nutrient management will have a paramount importance in enhancing agricultural productivity and ecosystem health in the parts of the country. In light of this, water harvesting is considered by many as an entry point to enhance agricultural productivity because if water is secured, the farmers in the dry areas will be encouraged to maintain soil fertility.

To mitigate the moisture stress during critical crop growth stages of the rain-fed agricultural production and to increase opportunities for irrigated agriculture afterwards, rainfed agriculture in the dryland areas needs to be supported by different water harvesting systems (Girmay, 2011). To this end, the Ethiopian government has been involved in the construction of different water harvesting structures in order to improve availability of the scarce water for both rain-fed and irrigated agriculture in Dryland areas. According to Fekadu et al. (2007), the issue of water harvesting was brought on board in Ethiopia since the famine in 1984. Initially it was micro-dams and river diversions which received top priority. This enhanced vegetable production but was limited to areas where there are micro-dams and river diversions. Lessons learnt from such efforts were taken to enhance the agricultural production. Initial ambitious plan of Tigray regional state, where the study area is found, was to construct 500 micro-dams in ten years though it was earlier considered difficult to construct micro-dams.

To alleviate the problem of drought and food insecurity in Tigray, the regional government has embarked on a conservation-based agricultural development strategy since 1991. The major natural resource conservation strategies include soil and water conservation investments on farmland, and the development of water harvesting schemes to store the runoff from catchments for either irrigation, livestock watering or domestic consumption during the dry season. Water harvesting activities are now wide spread in Tigray region with widely

recognized success stories in communities like Abrha Weatsbaha. The Abrha Weatsbaha community has been involved in the construction of various impressive water harvesting structures with a notable impact in the availability of surface and ground water for either supplementary and/or complimentary irrigation. In this study area, integrated water harvesting practices with main focus on trapping every drop of rainwater to the forms of groundwater recharging; enhancing soil moistures and reuse for multiple demands were employed. Prior to the restoration, the runoff and the floodwater leave the catchment eroding the topsoil, washing the nutrients, forming deep gullies with only rocks and barren land remaining behind(Hailu et al., 2012; Kifle et al., 2014; Tsegay et al., 2010). Thus, the community has spent days during the dry season working on their land and on the upper catchment to solve these problems and thus increase its water harvesting and storage capacity. Now with the ongoing intervention, heavy rains have become an opportunity to recharge the groundwater and serving as buffer for dry seasons. The indigenous knowledge of the community takes the largest share of the success that every practice is led by the community delegates and based on the local knowledge(WAC, 2013). Development of site-specific management strategies by involving farmers and extension workers/development agents is effectively employed. The extension system of the Bureau of Agriculture has also given a greater emphasis for integrated water resources management measures as part of general land management and productivity enhancing practices. However, the water harvesting structures which were constructed in Abrha Weatsbaha are not characterized and their performance is not evaluated so far. The physical characteristics of the structures, site suitability of the structures, the impact of integrated watershed management on water availability in the study area with respect to the intervention are not well documented. The main purposes of this study is, therefore, to appreciate the water harvesting techniques, evaluate and characterize the water harvesting structures and assess their impact on water availability and watershed development of the area.

## **2. Objective**

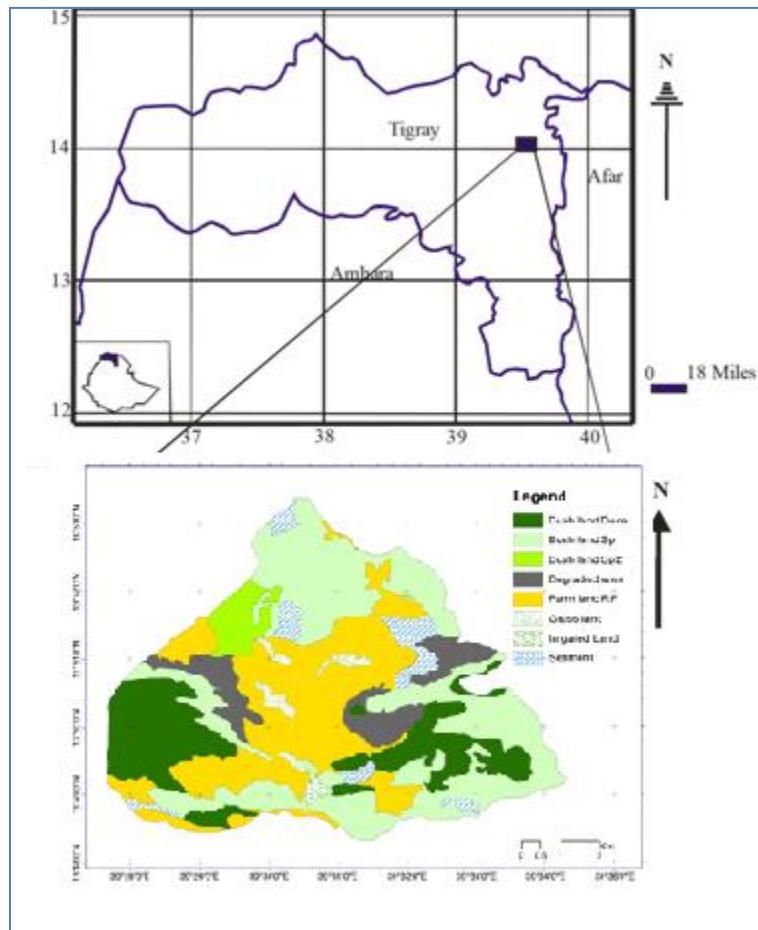
The main objective of the study was to characterize the major water harvesting structures in Abreha Weatsbeha and, thus, to evaluate their performance, site stabilities and effects.

Specific objectives are;

- ❖ To identify the water harvesting techniques practiced in the area;
- ❖ To characterize the major water harvesting structures;
- ❖ To carry out site suitability analysis and recommendations;
- ❖ To analyze the impact of the water harvesting techniques on watershed developments.

### 3. Study Area Description

Abreha Weatsbeha is located in Kelte Awelalo Wereda (WKA), Northeastern part of Tigray, Ethiopia. The study area is found at  $13^{\circ}51'12''N$ ,  $39^{\circ}30'28''E$  and Altitude of 1900-2600 m.a.s.l. Abreha Weatsbeha watershed (Fig. 1) includes three microwatersheds namely: Weyni, Mendae and Aret with total area of 6,766 ha. These microwatersheds drain to Suluh River which is the longest and the only perennial river of the watershed. The study area is in a long valley running approximately north to south between a sandstone ridge on the west and a basalt ridge on the east (Hailu et al., 2012).



**Figure1. Location Map of the Study Area.**

The study area is mostly hillside and mountainous (45.5%) with 21.5% of medium slope and the rest 34% is categorized as gentle slope where the cultivated land is found(WKA, 2014). The total population of the watershed is 5217 (Table 1) with 1186 households and 1023 land owner farmers. The female and male population is equivalent with slight increment in female population. The community is well known by Environmental re-engineering in practice and is a leading model in showing Sustainable Land Management in Tigray.

Table 1: Total Population of Abreha Weatsbeha

S/N	Category	Population		Total
		Male	Female	
1.	Total Population	2519	2698	5217
2	Household Heads	830	356	1186

Sources: (WKA, 2014)

### 3.1 Story of AbrehaWeatsbeha

The study area was categorized among the drought-prone areas afflicted by frequent hunger for many years. The rainy season in the study area lasts only two to three months (Table 2). Population increase had led to massive deforestation and overgrazing, resulting in land degradation and an increased vulnerability towards drought and food insecurity. The land had become so barren that the government has had no other choices than to relocate the community. In 1998, the Ethiopian government has then decided that the people of the village need to be resettled to a different area. The government offered the people with a new land management plan that to be carried out by their own workforce and the Ministry of Agriculture would support the restructuring with the help of international donors (Hailu et al., 2012; Kifle et al., 2014).

Since 1998, the community has embarked on implementing different methods of sustainable land management such as integrated soil and water conservation practices. Gradually, the change has become so boldly visible to the community, government and at large to the world that the area is dramatically turning into a green environment with sufficient access to water resources. Mr. Gebremichael Gidey, who is the chief of the village, is the initiator of the change and has become a well known man in Ethiopia. He has done what many believed impossible: to save his village from resettlement, thus creating a stimulus for the ecological rehabilitation of large land areas.

Since the community started the fight against drought and erosion, many things have changed in Abreha Weatsbeha. The groundwater table has risen from 15 meters to 3 meters depth even in the driest season. Nearly all farmers now have their own shallow irrigation wells. The community has used the term “water bank” for groundwater ponds to make clear that groundwater is much like a bank account: You have to make a deposit if you want to withdraw later(Hailu et al., 2012; Kifle, 2015).

Today, the villagers own and harvest water from different water sources (Fig.13) and cultivate cereals, vegetables and fruits (Table 5 and 6). They can harvest three times per year – often so much that they manage to get surplus for sale in the local markets. Nowadays, the big concern of Abreha Weatsbeha is not about more of a survival but rather is about owning sufficient water and electric power supply so that they can realize more production that can change their life.

The efforts of the community and the dedication of their leader have not gone unnoticed at national and international arenas. The people of Abreha Weatsbeha including their leader Mr. Gebremichael were awarded the UN Equator Prize for their outstanding work in 2012. In these all years, Mekelle University has been closely working with the community in different watershed management endeavors. It has got the recognition for the exemplary leadership and environmental transformation of the community. Abreha Weatsbeha is now expecting to host an international event on environmental management practices, in which its success will be a showcase of environmental rehabilitation for others from around the world.

### 3.2 Agro-climatology

The average weather condition of AbrehaWeatsbeha is categorized relatively as semi-arid agro- ecology with average temperature (T)  $21^{\circ}\text{C}$  and annual total rainfall ranging from 350mm to 600mm. The metrological information such as relative humidity (RH) of eight years (2002-2009), Rainfall (RF) of eighteen years (1992-2009), mean temperature of eighteen years (1992-2009) and Evapotranspiration ( $E_t$ ) (Table 2) were obtained from Wukro meteorological station, which is located about 20 Km from the study area. Almost all the precipitation falls in July and August with an average monthly rainfall of 203.66 mm and 210 mm, respectively (Table 2).

Table 2: Mean Monthly Average of Metrological Data of Abreha Weatsbeha.

Type	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
RF(mm)	0.5	2.0	17.5	30.1	24.6	43.0	203.7	210.6	24.6	5.3	2.9	1.1
T. ( $^{\circ}\text{C}$ )	17.7	18.6	20.1	21.0	20.4	21.3	18.8	18.3	19.2	17.9	15.8	15.5
RH (%)	43.4	40.6	41.9	46.1	46.1	45.3	75.9	77.1	48.1	46.8	47.3	43.1
$E_t$ (mm)	4.4	5.2	5.6	6.0	6.1	5.4	3.6	3.8	4.9	5.1	4.5	4.2

Source: (Tireza et al., 2013)

### 3.3 Soil Characteristics

The soil data was collected both from primary observation and examining the soil physical properties using feeling method and from secondary data. Most of the soil is sandy with good infiltration but poor water holding capacity (Hailu et al., 2012). The most important feature of soil is the soil texture. In general, the textural composition of the soil in the study area is 67%

sand, 25% loamy sand and only 8% clay(WKA, 2014). The soil is ideal for groundwater recharging and horticultural crop production during irrigation period.

#### 4. Classification of Water Harvesting Techniques (WHT)

A transect walk was made to identify the major physical water harvesting practices implemented in the watershed. Classification of the structures was made based on physical dimension measurement such as height, width, depth and volume. Physical characteristics of the catchment such as land use, slope, purpose and the way in which water is stored (reservoir, soil, container etc.) were also used to categorize. Dimensions were measured using a tape meter and a graduated stick. The major water harvesting structures and storage techniques were identified by direct measurement and observation, group discussions with experts and key leaders of the community such as watershed committee, chief leader, youth associations and farmers. The WHTs are categorized into eight based on physical dimensions and in to three based on their slope and purpose (Fig. 2). As per the general approaches of integrated watershed management, the WHTs have been implemented in (1) recharge zone where the structures are built in slopes more than 16%, (2) intermediate zone where the slope is in between 6 to 15%, and (3) discharge zone where water is utilized for different purposes in areas with catchment slope less than 5%. The main purpose of the structures is for enhancing infiltration and soil moisture; and reducing soil erosion, siltation and flood risks at the bottom hill of the catchment.

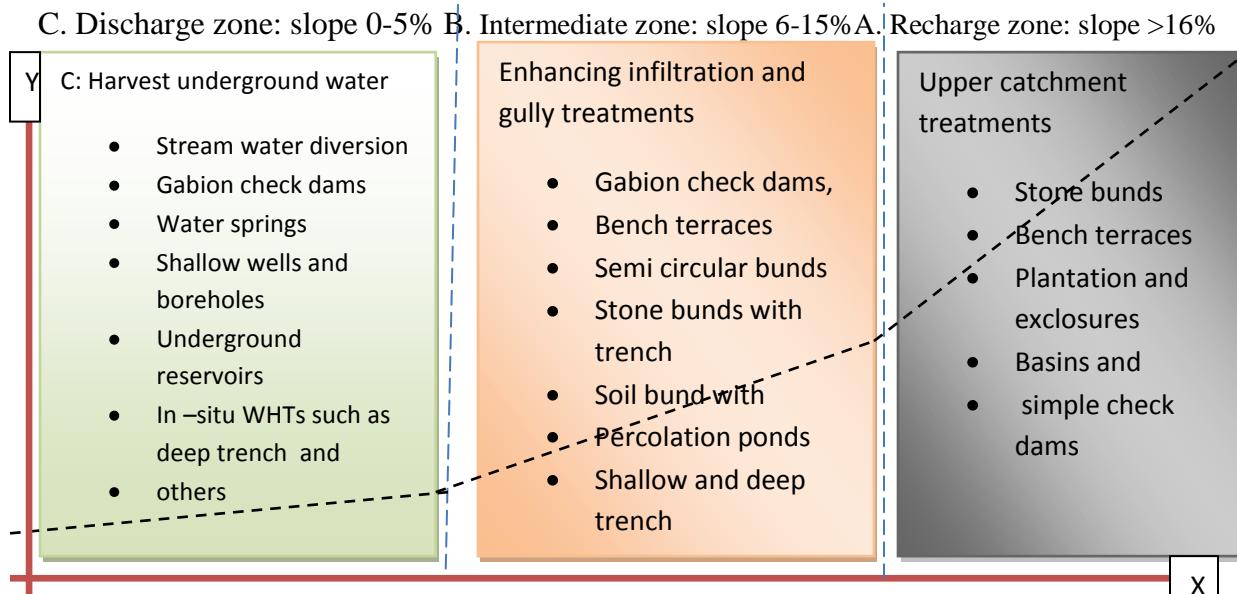


Figure 2: Schematic Approaches of Integrated Watershed Management in Abreha Weatsbeha

##### 4.1 Physical Characteristics

To select reliable WHTs which could be sustainable and effective under local circumstances, it is always necessary to understand the basic characteristics of the different WHTs (Bulcock and Jewitt, 2013; Lasage and Verburg, 2015). To characterize the water harvesting techniques,

this study considered major factors in determining the applicability and accessibility of the techniques. The water harvesting structures should technically be applicable under physical conditions in the field. Field conditions such as slope of the terrain, soil properties, geology, land use and land cover were collected both from primary (observation, measurements, individual and group discussion) and secondary methods from annual report of the wereda (WKA,2014), documentation of the study area (AWA, 2015). Characteristics of the structures- storage capacity, infiltration capacity, purpose of the structures, acceptability, and cost per head work was determined and analyzed. To understand the physical characteristics of the major WHT detailed measurements including their specific location was carried out using tap meter and GPS.

#### **4.1.1 BENCH TERRACE**

Construction of bench terraces is one of the recent and most important WHT employed in the study area (Fig. 3). The main purpose of the bench terraces was to reduce the slope length, minimize runoff and soil erosion, and enhance soil moisture and thereby increase crop and forage production on the pieces of plots (Fig. 3). It was also observed that the structures have great impact on rehabilitation of the degraded land and restoration of the hillsides. They are most effective in hillsides with slopes 15%-40%. From the measurements that have been carried out, the top width of bench terraces was found to be 20-140cm, their height ranged from 65cm to 170cm and the spacing between rows was 3.2m in areas with very steep sloped and 15.5m in areas with a slope less than 15% (Table 3).

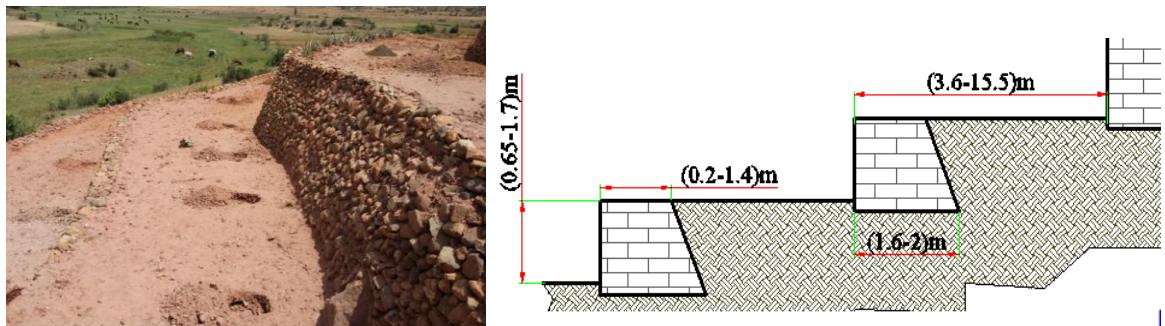


Figure 3: Bench Terraces in AbrehaWeatsbeha: Cross section view (right)

Tigray regional state Bureau of Agriculture is the one that provides specifications of the designs of such structures. The dimensions that are provided from the Bureau of Agriculture (AWA, 2015) include a basement width of 1.6m, top width of 50 cm, height of 1.5m and spacing between consecutive structures ranging from 3 to 6m depending on soil type and slope. However, this study revealed that the dimensions have slight changes from recommended standards of the bureau as the structures are constructed based on local knowledge. These dimensions are blanket values, which didn't consider other factors such as geological formation of the command area. What makes the construction of the structures really impressive in the study area is the creativity of the community in that the dimension varies as the geological formation also varies.

#### **4.1.2. STONE BUNDS**

Stone bunds are constructed following the contour of the micro-watershed. The main purpose is to reduce the slope length, slow down and filter runoff, thereby increase infiltration and capture sediments(Seleshi et al., 2009). The water and sediment harvested lead directly to improve the soil depth, soil moisture and fertility and thus motivate tree plantation and production. The technique is recommended in farmer's fields with a slope between 2 to 5% and an area with adequate supply of local materials such as stones. However, in Aberha Weatsbeha the structure is modified that it can be well adapted in any type of land use even in hillsides with slopes up to 40 %.

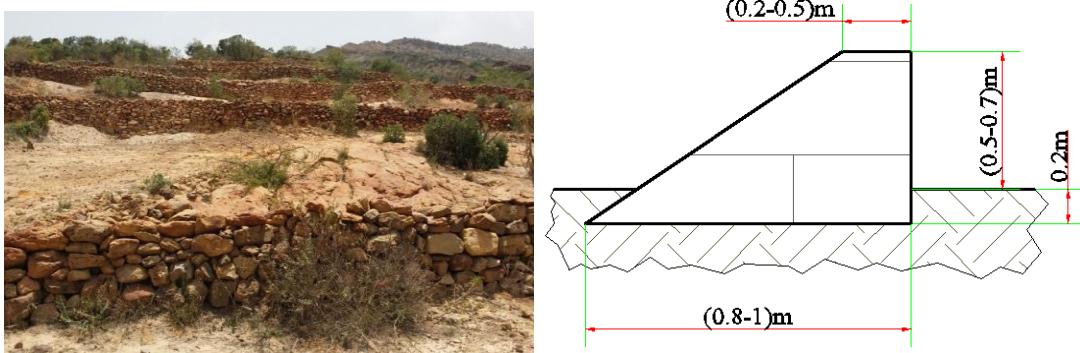


Figure 4: Stone Bunds in: Cross Section (Left)

Although it is simple to construct, a minimum bund height of 65 cm, with a base width of 80–100 cm (Fig.4) is recommended. The bund contains a shallow trench on the upper side with a depth of 15–30cm, which helps to adequately trap runoff and sediments. The bunds are constructed with smaller stones placed upside of the larger ones constructed as retaining wall to facilitate rapid siltation. Average bund spacing of 12.75m was measured. The spacing between bunds ranged between 8.7(slope up to 40%) and 16m (slope less than 15%) depending on stone and labour availability. Generally, as the slope increases, the spacing between stone bunds decreases.

#### **4.1.3. STONE BUND WITH TRENCHES**

Stone bunds with trenches are constructions of stone embankment following a contour at the downside and digging of the trench at the upper side of the stone bunds. The physical description of the structures is that a foundation up to 20 cm is dug and stone wall is constructed with height of 50-70cm, bottom width of 50-100 cm and spacing between rows of 20-23m. A series of trenches are then constructed along the contour of the stone bunds with depth of 40cm, width of 65-70cm and spacing of 50cm (Fig.5). The purpose is usually to decrease slope length, minimize soil erosion and reduce runoff velocity thereby increase moisture harvesting, and productivity per unit area. In addition to their physical characteristics, it is observed that their effectiveness is high in areas with a slope of 0-30%

and where fodder trees are planted and integrated with other biological measures. In the study area, stone bunds with trenches are most common water harvesting practices particularly in cultivated land and hillsides of the catchment. Their impact is now manifested in the growing natural grasses and vegetation, minimized desertification, improved ground water recharge and in the improved local climate.

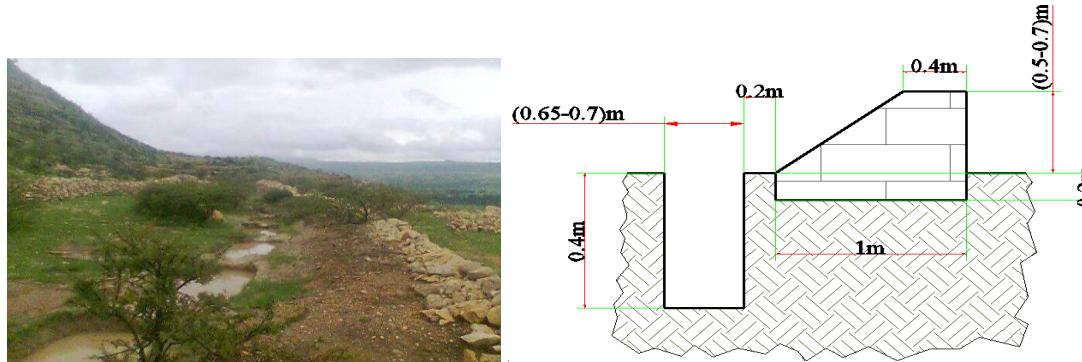


Figure 5: Stone bunds with trench in Abreha Weatsbeha watershed

#### 4.1.4 SOIL BUND WITH TRENCH

Soil bunds with deep trenches are ridges and ditches made of soil dug across the contour slope of the catchment (Fig. 6). They are constructed for the purpose of minimizing run-off, reducing soil erosion, enhancing soil moisture and thereby improving productivity. This technique is well suited in areas of both cultivated and grazing lands with slopes 0-5%. Their construction is very simple in that it can be carried out by the local knowledge of the community. The width, depth, length, and spacing within trench and in between bunds are determined based on the soil type, slope and land use (Table 3). For instance, in the cultivated areas the size of deep trench is 50cm (depth) x 300cm (length) x 50cm (width) but in grazing lands the size of one deep trench is 100cm (width) X 50cm (depth) X 300cm (length). The standard of the spacing in between trenches is 100cm though the dimensions can be altered after a while. The spacing between rows of contour bunds is ranged from 20.5-22m (Table 3).

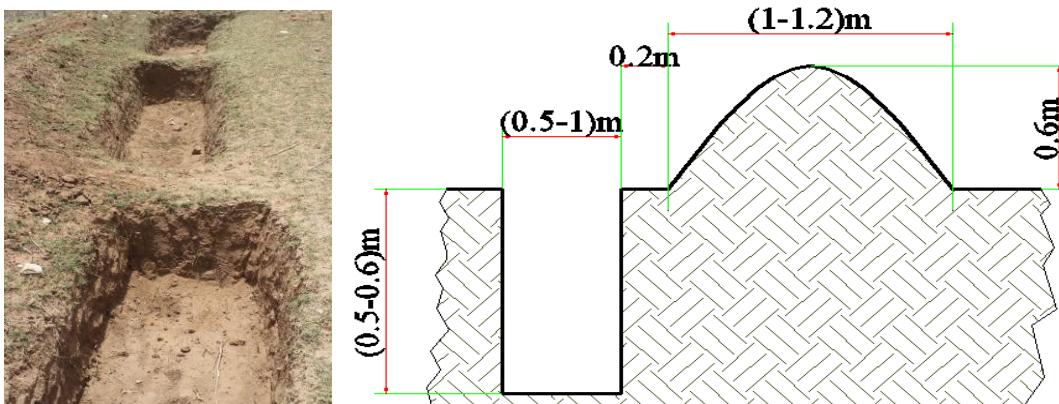


Figure 6: Soil Bund with Deep Trench: A) Cascaded Deep Trenches B) Cross Section

Since the soil is sandy and its depth is more than 2m, deep trenches have the ability to store and infiltrate high amount of rainwater. According to Terizea et al 2013, an individual structure is capable of capturing more than 765.85m<sup>3</sup> of rain water per annum.

#### 4.1.5 SEMI-CIRCULAR STONE BUNDS

Semi-circular bunds with stone embankments are in the shape of a semi-circle with the tips of the bunds on the contour (Fig. 7). They are used mainly for rangeland and bush land rehabilitation. They also serve as points of ground water recharge. The technique is also used for growing trees and shrubs and, in some cases, has been used for growing fruit trees.

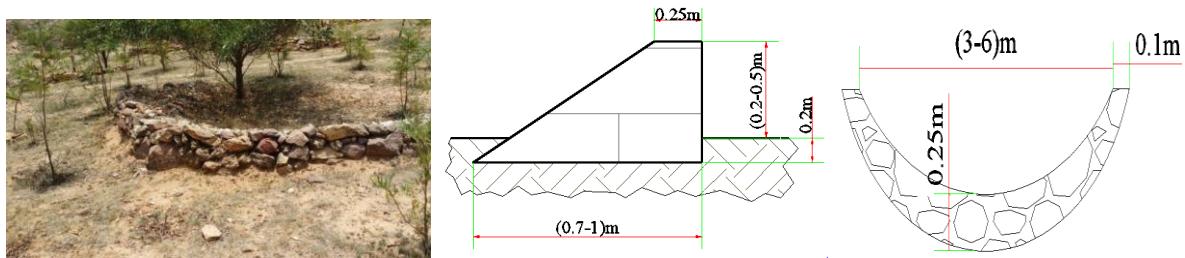


Figure 7: Semi-Circular Bunds with Acacia Tree

The technique is suitable for slopes of less 5% and consists of a series of small semi-circular bunds with radius of 3-6 meters. The size of the radius varies with area of upper catchment where the runoff is generated and, of course, the slope. They are constructed in staggered manner with overflow producing catchments in between structures thus allowing the collection of runoff from the area between the bunds above. The measured dimensions of semi-circular bunds in the study area are: 25cm height with side slopes of 1:1 which result in a base width of 75 cm at a selected top width of 25 cm (Table 3). The tips of each bund are set on the contour, and the distance between the tips of adjacent bunds in the same row is 3 meters. Bunds in the row below are staggered. The distance between the two rows, from the base of bunds in the first line to tips of bunds in the second, is 3m.

#### 4.1.6 Percolation Pond

In Abreha Weatsebha more than 73 cascaded percolation ponds are constructed. These series ponds (Fig. 8-B) are usually made up of earth embankments. They are intended to impound and increase the residence time of harvested floodwater. The structures are used to slow down and store floodwater-which has been generated from the hillside of the catchment with high velocity and erosivity, and accumulate sediments. Their ultimate goal is to recharge the ground water for later use for irrigation and other domestic purposes as groundwater sources. Their significance in raising the water table (In general to increase access to water) is believed to be more than any other WH structures in the study area. On average each percolation pond has the capacity to contain and infiltrate more than 5,025 m<sup>3</sup> of rainwater per year(Tireza et al., 2013). The physical characteristic of the percolation ponds in the study area was analyzed using surveying and mapping instruments and observation. On average the volume of the

ponds varies from 956 to 1882 m<sup>3</sup>. Though the ponds have accumulated high amount of sediments, an infiltration pond with a maximum depth of 3.9 meters was observed. The structures are constructed using machines with the help of Tigray Regional State Bureau of Agriculture.

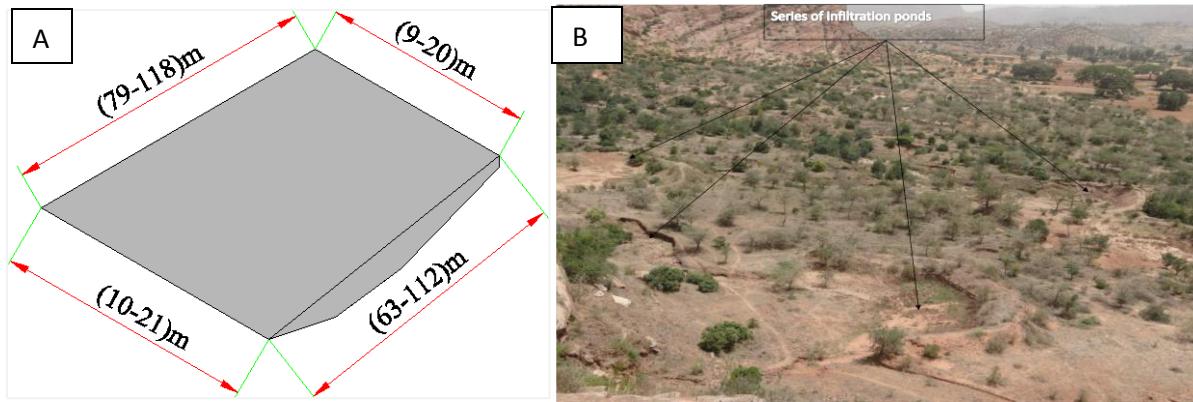


Figure 8: Cascaded Percolation Ponds: A) Cross Section B) Schematic Map of Typical Percolation Ponds (Kifle, 2015)

Table 3: Observed Physical Water Harvesting Structures' Dimensions

WHT	Slope %	Land Use	Dimension	Ave.	Min.	Max.
Stone Bund With Trench		Cultivated	Height Of Stone Bund (cm)	61.25	50	70
			Top Width Of Stone Bund (cm)	36	20	50
			Spacing Between Rows (m)	21.75	21	23
			Depth Of Trench (cm)	40	40	40
			Width Of Trench (cm)	68.75	65	70
			Spacing Between Trenches (cm)	50	50	50
Stone Bund		Bush Land	Length (Cm)	287.5	270	300
			Height (Cm)	65	50	75
			Width(Cm)	74.28	60	80
Soil Bund With Trench	4	Cultivated	Spacing (m)	12.76	8.7	16
			Width Of Trench (cm)	75	50	100
			Depth Of Trench (cm)	55	50	60
			Length of Trench(cm)	2.5	2	3
			Spacing between Trenches (m)	1	1	1
Bench Terrace	40	Hillside	Spacing Between Rows (m)	21.25	20.5	22
			Height (cm)	122.08	65	170
			Width(cm)	65.83	20	140
Bench Terrace	30	Bare Land and Hillside	Spacing (m)	8.43	3.6	15.5
			Height (cm)	144.37	110	170
			Width(cm)	91.25	70	120
			Spacing (m)	5.24	3.2	12.4
Check Dam		Drainages	Height (m)	1.87	1	2.4
			Crest Width (m)	0.9	0.8	1.1
			Basement Width (m)	4.01	2.4	8.5
			Length of the Crest (m)	20.95	15	27.8
			Free Board (m)	1.01	0.75	1.2
Shallow Wells	4	Cultivated	Diameter: Top (m)	6.74	5.2	8.2
			Diameter: Bottom	4.5	3	6
			Minimum Depth Of Water (cm)	95.3	30	250
			Depth Of Well (m)	6.5	3	10
			Maximum Water Depth (m)	3.35	2.7	5

Where: Ave.= average dimension, Min. = minimum dimension, cm = centimeter, m= meter and Max.= maximum dimension

#### 4.1.7 CHECK DAMS

In Abreha Weatsbeha next to shallow wells check dams cover large portion of irrigation lands (Fig. 9). WKA(2014) has documented about 55 check dams. The structures are successive and constructed along the various watercourses of the catchment all the way down the hill. The community has constructed check dams with bundles of stones and gabions cemented with

mud. The aim is to collect portion of the running water for irrigation but in the meantime could help to recharge the ground water and accumulate sediments. To protect the structures from damage by flood, other similar barriers with spacing 35 to 40 meters in-between has also been constructed up the hill. Spillways (Fig. 8 (a)) have been left to the side of the pond that would allow excess water to continue flowing out.



Figure 9: Check Dams in Aberha Weatsbeha A) Check Dam during construction B) Check Dam after It Stored Water

The technology is very useful that the community is now able to tap groundwater at a depth of 3 to 4 meters in exactly the same places where the water table was used to be deeper than 15 meters and with low yield. Every check dam has the ability to harvest annually about 5,012.6m<sup>3</sup> of rainwater (Tireza et al., 2013).

#### **4.1.8 Diversion Head**

It was mentioned earlier that every drop of water of the watershed is used in integrated approach. Like other water harvesting techniques, river diversion works have also played significant role on irrigation development. Two structures are constructed across the water course of Suluh River with a total length of 3 km lined canal ( $1500\text{m} \times 2 = 3\text{km}$ ) and can irrigate an area of 57.75ha.

#### **4.1.9 HAND DUG WELLS**

Around 388 hand dug wells were dug out along this catchment area where people are carrying out irrigation practices using the water from the wells (AWA, 2015). However, due to groundwater overexploitation some of the wells especially those on the upper catchment are drying up and currently only 320 wells are functional. Of these, 300 wells are serving for irrigation and the other 20 for domestic water supply. The wells are classified into three groups based on their construction: (1) unlined, (2) lined and semi lined with masonry only and (3) lined both with masonry and cement. About 15 shallow wells were investigated. Of these 90 % are lined with Masonry (Fig. 10 (C) and 5% are lined with Cement and Masonry while less than 10% of the observed wells are unlined (B).

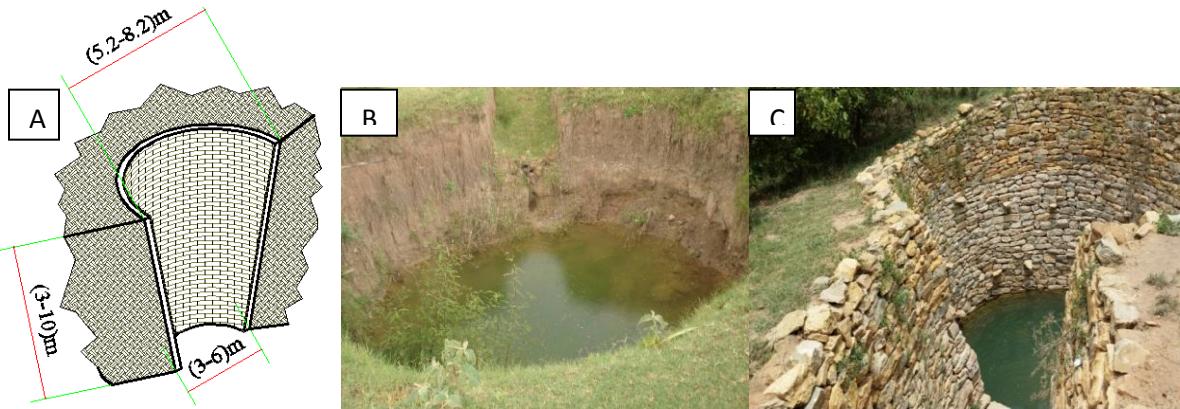


Figure 10: Shallow Hand Dug Wells in Abreha Weastbeha: A) Section of Well B) Unlined Shallow Well, and C) Lined with Masonry well

According to Teriza et al, 2014, every hand dug well has the ability to yield on average 14,795m<sup>3</sup> of water per annum. The white mark in Fig.10(C) on the side of the well is an indicator of how the water stored rises to maximum depth 1-2m below the surface during September- December. The difference is visible in that before the intervention (1998GC), the ground water table was 15m (Kifle et al, 2013). As reported by AWA (2015) and also observed in the field, all functional wells yield water throughout the year. However, the depth of the water inside the wells will be minimum and could reach as low as 30cm during April to May. Though the groundwater potential is rich enough, the communities have concerns over the balance of demand and supply of water. To solve these problems solutions have been suggested that include:

- Putting in place rules which limit the number of wells to be owned by individuals and the distance between these wells i.e., currently every farmer of the community can dig as many wells as they like.
- Constructing deep boreholes is necessary because the population is increasing from time to time, as per the group discussion, and the demand for water accordingly is increasing and the existing shallow wells don't satisfy the ever increasing demand for water in the area.

In General, the basic interest of the community is to maximize their productivity by reducing the number of hand dug wells and optimizing the depth of wells to be dug.

#### 4.2 Socio- Economic Characteristics

Resources necessity for construction versus existing water harvesting structures was assessed to investigate the acceptability and feasibility of the technologies. In this case the investment costs, raw materials, labor (both skill and local), technical complexity, policy direction of the government, governance of the watershed and maintenance are the major parameters that were covered in this study to examine the overall socio-economic characteristics of the catchment. The acceptability and lifetime of the structures were also studied by conducting semi-structured questionnaire.

Raw materials such as stone are supplied from the bedrocks of the watershed using human labor: men crush the stones and women carry them to the construction sites (Fig.12). However, materials such as gabion and cements are supplied from the government (Tigray Regional State Bureau of Agriculture Development and Agricultural Extension).

Though enough input materials are available and are provided by the government, the commitment, motivation and leadership of the community makes it absolutely successful when compared to other similar watersheds. The watershed development of the study area is highly dependent on human labor. Fig.11 and 12 are evidences that every activity in the community is labour intensive. For instance, Fig.11 (A) shows how individual farmer irrigates the farmlands using treadle pump and Fig.11 (B) indicates the challenge that farmers face in accessing the market through local transportation.

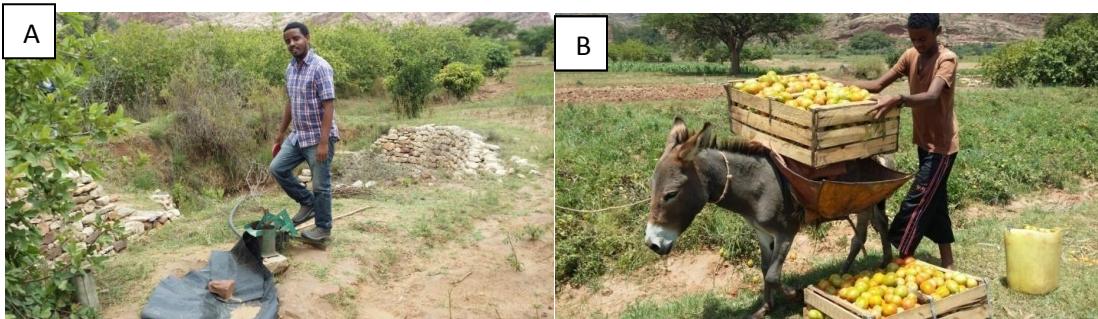


Figure 11; Irrigation Practices of Abreha Weatsbeha: A) Treadle Pump Water Lifting for Irrigation, and B) Means of Transportation

Leadership was key in the successful watershed management in the study area. Aba Hawi (the chief leader of the development), during group discussion, was full of enthusiasm and energy to explain the hurdles and the great efforts made by the community. He has never been to school or received any formal education on integrated natural resource management. But from his natural talent he has engineered all the structures including their complexities. He strongly believes the success is the result of unreserved effort by the community. However, the people of the community are indifference from their leader in that they were there for centuries and believe that the mystery is from the exemplary leadership. In Abreha Weastbeha, gender equity is well exercised practically than is used elsewhere for lip services. During the group discussion, the participants (particularly the female participants) including the chief leader underlined that about 70-80% of the success counts to the female population of the community. In general, the community's success is the result of quality leadership, commitment of the people and government policy directions. They are well organized to different watershed development activities such as when to construct new technologies and where and when to maintain WHT. They adopt new technologies very easily and carry out every design modifications appropriately and maintain the structures on time on their own.

From field measurements and group discussions with the community, the construction costs of the various WHTs were estimated. Because almost all the watershed development activities

are done as free service (a minimum of 20 days every year), the construction costs have been determined based on the average wage rate and material cost in the study area. Accordingly, the average cost per volume ( $1m^3$ ) and/or per a unit length (1m) has been estimated and is presented in Table 4. For instance, to construct 3m length of Stone Bund with Trench in one day, three daily laborers are required. This means that labor cost is  $3*\$4=\$12$  and the cost of masonry per unit volume is (if the volume of masonry for three meters long, 70cm height, 1.6m bottom width and 50cm top width is  $2.73m^3$  and the unit cost is \$6.25)  $2.73*\$6.25=17.0625$ . The unit price is, therefore, estimated to be \$5.687 per meter work of both stone bund and the deep trench along.

Finally, the community distributes every benefit from the watershed activities equally to everyone involved in the intervention. For example, sand accumulated on the check dams ( $560m^3$ - $640m^3$  volume of sand every year), and honeybee and fruit trees production from area closures are shared among members of the youth association established in the area.



A) Community Participation in Construction Material Collection



B) Check Dam Maintenance

C) Group Discussion with Community Members

Figure 12: Community Participation in Abreha- Weatsbeha

## 5 Site Suitability Analysis

A site suitability analysis for the different water harvesting structures in the study area has been carried out using the soil texture, slope, rainfall, geology, land use and the purpose of the structure. Based on the field survey, measurements and the community recommendations (local knowledge) the site suitability analysis has been summarized in Table 4. Since the soil is sandy, deep trench, check dams and percolation ponds are the most effective water

harvesting structures in this study area. If the structures are classified based on slope of the catchment area and their purpose for water harvesting (Fig. 2), WHTs such as stone bunds and bench terraces are found to be very effective in the upper catchment (slopes up to 25-40%). All the other WHTs are located in areas with less than 25% slope and are successfully harvesting rainwater in the study area. Check dams, percolation ponds, and stone bunds with trenches are very useful at the middle slopes (5-25%) of the watershed. For the gentle slopes (0-5%) especially in the cultivated and grasslands, deep trench and semi-circular bunds are found to be the most common practices.

The slope, soil depth and soil texture of each land use also affect the dimension of the water harvesting techniques (Table 3 and 4). For example, stone bunds with deep trenches are constructed on hillsides with slopes up to 40% and serve their purpose effectively. They are also constructed on farmlands with slopes up to 5%. The construction of stone bunds on the farmlands is feasible if the raw materials for construction are available otherwise soil bunds with deep trenches are used as other options in cultivated lands with slopes less than 5%.

The structure is capable enough to reduce slope length and thus increases infiltration and decreases runoff thereby decreasing soil erosion and flood risks at the downstream of the watershed. In terms of purpose, shallow wells are among the common and best performing of water harvesting techniques in the study area. A single shallow well can on average cover up to 2ha of irrigated land. Next to shallow wells, check dams and river diversions are also playing an important role in irrigation development of the study area .A single diversion head for instance has the potential to irrigate an area of more than 28 hectares. As the water sources of shallow wells and check dams are located lower than the command areas, almost every farmer is using generators (motor pumps, and /or treadle pumps) to irrigate his /her farmlands.

If the impact of all the aforementioned water harvesting techniques is summed up, they have significantly changed the watershed development with two main tasks. In one hand, they reduce risk of runoff/ erosion at downstream/flood plains and sediment deposition. On the other hand, they increase access to water through groundwater recharge.

## **6 The Impact of Water Harvesting Techniques**

The impact of the various WHTs was assessed using field survey, individual and group discussions, secondary data from reports of the woreda and the study area (KAW, 2014and AWA, 2015). The impact measurement and analysis were carried out considering agricultural production; access to water (i.e. the amount of water supply for domestic, irrigation and sanitation); and environmental rehabilitation (i.e. land use and land cover changes), and land rehabilitation. This study also considered the impact of WHTs on groundwater recharge (the main sources of water in the study area). The amount of water that infiltrates due to the various water harvesting structures was determined from the water balance equation and the change in depth of the water table to the ground surface by direct measurements.

Table 4: Site Suitability Analysis of Water Harvesting Techniques

Name	Land use	Slope %	Purpose	Construction per Head (USD)	Cost
Deep Trench	Any	0-5	Moisture conservation Ground water recharge	\$3.5/ m <sup>3</sup> volume	
Stone Bund	Hillside	15-40	Land rehabilitation Reducing slope Reducing runoff risks	\$3.5/ m <sup>3</sup> volume	
Bench Terrace	Hillside	25-30	Fruit production Land rehabilitation Runoff reduction Groundwater recharge	\$14.4/m <sup>3</sup> volume	
Stone Bund with Trench	Hillside	0-30	Reducing runoff Moisture conservation	\$5.687/m length	
Earthen Bund with Trench	Cultivated land	0-5	Moisture conservation Reducing runoff	\$3.5/ m <sup>3</sup> volume	
Semicircular Bund	Bush land Bush lands	0-5	Reducing soil erosion Groundwater recharge Runoff reduction	\$3.5/ m <sup>3</sup> volume	
Check Dams	Along streams	Any	Irrigation Gully rehabilitation Erosion protection Mining	\$4000/head	
Percolation Pond	Bare lands	0-5	Ground water recharge	Unknown *	
Hand Dug Wells	Cultivated land	0-5	Irrigation domestic and water supply	\$2000-6000/head	
Hand Pump Wells	Any	0-15	Water supply	\$6000/head	

\* Percolation ponds are constructed by government

## 6.1 Agricultural Production

From the group discussion it was found that there are three cropping seasons in Abreha Weatsbeha. The first is rainfed production during the summer (from June to October). The other two are irrigated production (October- February and March –June). As per the KAW census of 2014, the most common types of crops grown in the study area are cereals, vegetables and fruits in both rainfed and irrigated production. The cultivated land, yield per

hectare and yield per year for each crop in the study area are summarized in Tables 5&6. Some crops such as Maize, Teff, Barley and Wheat are commonly harvested in both rainfed and irrigated production systems (Table 5). The annual production of the watershed is estimated to be around 81134 quintals from which 78% comes from irrigation and the rest 22% is from rainfed.

**Table 5: Cereal Production of Abreha Weatsbeha**

Crop type	Rainfed			Irrigation		
	Area Coverage (ha)	Yield (Quintals)	Yield per ha	Area Coverage (ha)	Yield (Quintals)	Yield per ha
Wheat	193.5	7132.56	36.86	13	448.5	34.5
Barley	84.75	2415.37	28.5	21.5	354.8	6.5
Teff	135.25	1859.25	13.75	39	468	12
Hanfets	48.5	1406.5	29	--	--	--
Millet	57.5	1265	22	26.5	715	26.98
Finger millet	22.5	427.5	19	--	--	--
Maize	11.75	313.5	26.68	103	3178.5	30.86
Been	4.25	63.25	14.88	14.3	203.1	14.2

Source: WKA, 2014

In addition to the aforementioned production system, livestock and honeybee productions are also other sources of income in the study area. Within the watershed around 1500 ha of land is reserved as an area closure for land rehabilitation. Such area closures are serving as forage and grass sources for livestock and honeybee production by the youth associations. There is also a central protected grazing area with a rich biodiversity which also is contributing its share for livestock production (Hailu et al., 2012). These production systems are now boosting compared to the years when water was scarce even for domestic water supply. The total livestock production of the watershed reaches more than 8784 heads and there are about 1490 beehives in the area (Fig.13).

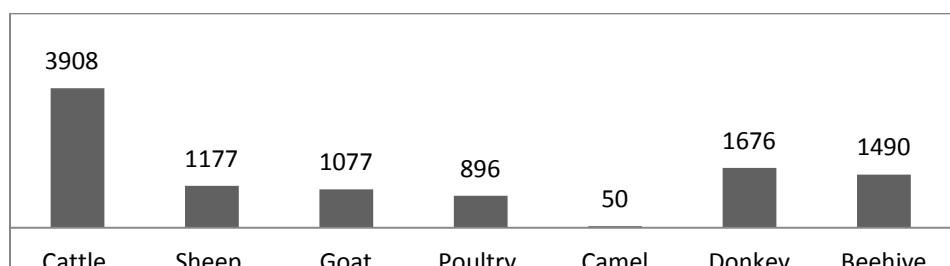


Figure 13: Livestock Production of AbrehaWeatsbeha(WKA, 2014).

The major livestock productions in the study area include cattle, donkey, sheep and goats (Fig.13). Cattle and donkeys dominate livestock production because cattle are used for ploughing and donkeys are used for transportation. Because of the regeneration of indigenous

trees in area closures and the availability of water in the catchment area, honeybee production is becoming one of the dominant production systems.

### 6.1.1 Irrigation Development

In Abreha Weatsbeha, irrigation is becoming a common practice. More than 1023 farmers are using irrigation to produce cereals, beans, vegetables and fruits. Irrigation is practiced twice a year and about 460ha of land is being cultivated every year (WKA, 2014). As per the group discussion with the community members, what was a barren and degraded land with no irrigation practices 15 years ago is now largely under irrigation. Irrigation practices such as furrow for vegetables and corns, border irrigation for cereals and beans, point irrigation (i.e. manual application of water for individual trees) for fruits are the most common in the study area. The water sources for irrigation mainly come from groundwater sources. About 57% is contributed by shallow hand dug wells, 20% from check dams, 13% from diversion heads and 10% from farm ponds (Fig. 13). During rainfed production, spate irrigation is also used as a technique to supplement with the extra water required by the crops.

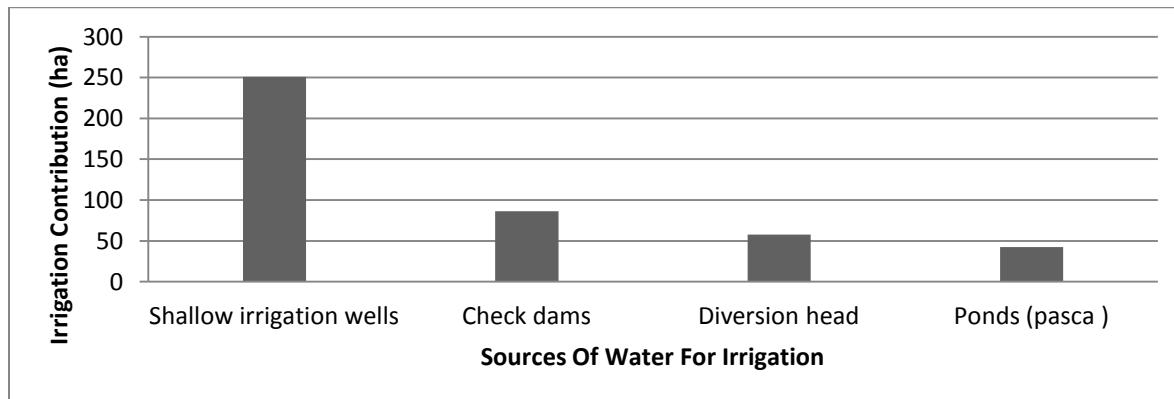


Figure 13: Sources of Water for Irrigation

During irrigation period, tomato (210.3q/ha) and pepper (112q/ha) from vegetables and guava (317q/ha) from fruit trees cover the largest share of the production and are the largest income generating commodities for the community (Table 6).

Table 6: Irrigation Coverage and Production of Vegetables and Fruits in the Study Area.

Type	Vegetables			Fruits			
	Area (ha)	Yield (Quintals)	Yield per ha	Type	Area (ha)	Yield (Quintals)	Yield per ha

Tomato	172	36173	210.3	Guava	10.25	3250	317.07
Pepper	97.5	11895	122	Orange	12	1251	104.25
Cabbage	8	1920	240	Lemon	5	1040	208
Spinach	11.5	1495	130	Avocado	5	880	176
Lettuce	10	1200	120	Papaya	1	530	530
Garlic	11.5	1035	90	Mango	5	196.75	39.35
Onion	6.5	715	110				

Source:(WKA, 2014)

### 6.3 Domestic Water Supply

Since the implementations of different water harvesting technologies, the total water supply coverage of the watershed has reached about 96% (WKA, 2014) with a travel time to water sources of 25-30 minutes. The average daily domestic water supply per household of the watershed is estimated to be 100 litter/day. The source of water supply is 100% from groundwater through shallow hand dug wells (56%), shallow boreholes (30%) and the other 14% from springs and deep wells. Because the geological water bearing formation is sandstone, the water quality is expected to be good for domestic use. However, the people of the community have complaints on the quality and quantity of the water during April and June (the hottest period of the year). In these months the depth of the groundwater table decreases up to 10m below the ground surface. This leads to an increment of the turbidity of the water as the water depth gets closer to the bed of the wells. Coupled with this as the population is increasing from time to time, the demand for water is also increasing.

### 6.2 Land Use and Land Cover Change

The study area consists three microwatersheds namely: Mendae, Weyni and Aret. The land use and land cover changes for the last 12 years have been determined using ArcGIS (Fig. 14) with 1998 and 2010 imageries. Accordingly, the entire watershed was classified in to six land uses specifically: bare land, grazing land, cultivated land, bush land, irrigated land and area closure.

Before 1998 the land degradation, deforestation and drought condition of the study area were sever (Kifle, 2015; Seleshi et al., 2006; Tsegay et al., 2010; WAC, 2013). Similar studies emphasized the susceptibility of the study area for soil erosion and consequent gully formation as the soil texture is sandy and more than 48% of the watershed is a hillside (WKA, 2014). In the group discussion, it was learnt that gullies up to 11m deep below the ground surface were common (Fig. 15A). As indicated in Fig.14, the land use in the study area before intervention (1984G.C.) was with a proportion of 34% bare land, 32% cultivated land, 32% bush land and 2% grazing land of the total area.

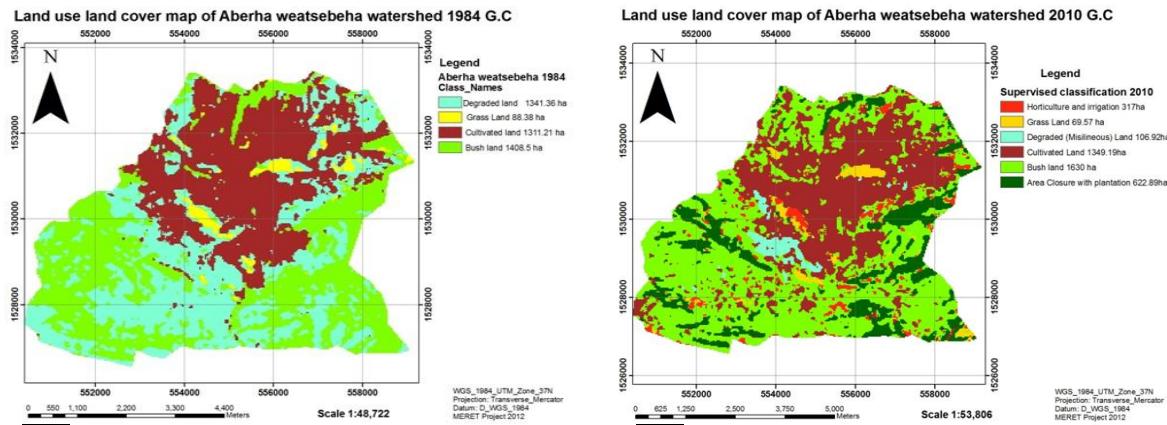


Fig 14. Land Use land Cover Change of Abreha Weatsebeha from 1984 (A) to 2010 (B).

However, after the huge commitments paid by the community, almost all degraded areas are rehabilitated and the change is now evidently clear. Restoration of natural vegetation, planting fodder trees, and protection of existing shrubs and trees have changed the watershed from a highly degraded land to an evergreen environment. Now, almost all the gullies have been rehabilitated and the streambeds are being used to plant different species of trees.



Figure 15: Impact of WHT on Successful Gully Rehabilitation A) Before Intervention (GIZ, 2010), B) During Intervention (GIZ, 2010) and C) After Intervention (observed in 2015).

After the intervention has been carried out for the last 17 years (1998-2015), the assessment shows a dramatic change in land use land cover and new land uses such as area closure and irrigated lands are introduced in hundreds of hectares. In these 17 years of intervention, the land use land cover change is tremendous. Bare lands have been drastically reduced to 2% while cultivated lands, bush lands, area closures, and irrigated lands increased up to 33%, 40%, 15%, and 8% respectively. However, the analysis shows that the grazing lands remained unchanged.

Generally, due to the intervention, land degradation is magnificently reduced. The vegetation cover of the watershed has shown a remarkable increase and has become one of the best examples in the world in terms of rehabilitating a degraded land. The catchment is now becoming a center for wildlife production. As a result, the regional government is planning to establish ecotourism sites within the catchment.

### 6.3 Hydrology

When intensive water harvesting techniques are practiced, the hydrology of the watershed (especially the runoff and groundwater recharge) is expected to change. To examine the impact of water harvesting techniques on runoff change, the SCS-CN model is selected. Details with regard to SCS-CN are found in NRCS (2004), Luxon and Pius (2013) and Taye et al (2014). The method is recommended in areas with different land uses because of its simplicity to apply in data scarce areas, and take into consideration the physical and hydrological conditions of a catchment. The input components of the catchment such us long term average annual precipitation, catchment area, land use land cover changes before and after the interventions together with soil texture classification were used to determine the hydrological soil group and thereby compute area weighted CN for the watershed as follows.

The runoff for each land use was estimated as;

$$I_a = 0.2S \quad \dots \dots \dots \quad (\text{Eq. 1})$$

Establishing a relationship between  $I_a$  and  $S$  for a specific watershed requires more data on rainfall and runoff, but can be assumed to be a function of the maximum potential retention,  $S$  as is indicated in NRCS (2004). Thus, an empirical relationship between  $I_a$  and  $S$  was expressed as;

$$I_a = 0.2S \quad \dots \dots \dots \quad (\text{Eq. 2})$$

$$S = \frac{P - I_a}{0.2} \quad \dots \dots \dots \quad (\text{Eq. 2})$$

And  $S$  is given as;

$$S = \frac{P - I_a}{0.2} \quad \dots \dots \dots \quad (\text{Eq. 3})$$

Where,  $S$  = potential maximum retention (mm)  $Q$  = accumulated runoff depth (mm),  $P$  = accumulated average annual rainfall depth (565mm), and  $I_a$  = initial abstraction (mm).

The Runoff volume of the catchment before and after the treatment of the catchment is then estimated as area weighted average runoff of the land uses,

$$Q_A = \frac{\sum A_i Q_i}{A} \quad \dots \dots \dots \quad (\text{Eq. 4})$$

Where,  $Q_A$  = area weighted runoff (mm),  $A$  = total area of the catchment (ha) and  $A_i$  = the area of land uses (ha)

$$\dots \dots \dots \quad (\text{Eq. 5})$$

Where,  $Q_v$  = run off volume ( $m^3$ ),  $Q_A$  = run off depth (mm) and  $A$  = catchment Area (ha)

Table 7: Runoff Response Before and After Water Harvesting Interventions

<u>Before intervention</u>				
Land Use	Area ( ha)	HSG*	Hydrological condition	Q (mm/year)
Cultivated land	2029.8	A	Poor	156.66
Bush land	2300.44	C	Poor	169.54
Grazing land	135.32	B	Poor	9.89
Bare land and homestead	2300.44	D	-	188.40
<u>After intervention</u>				
Cultivated land	619	A	Good	37.39
Bush land	3140	C	Good	156.01
Grazing land	206	B	Good	15.06
Bare land	133.52	D	Fair	10.93
Homestead	1071	D	-	83.25
Area Exclosures	1500	C	Good	110.55

\*HSG stands for hydrological soil Group.

As shown in Table 7, though the CN method doesn't consider the intensity and all types of interventions, surface runoff has been reduced by 21.22%. This reduction in surface runoff is mainly due to integrated watershed management implemented in the study area. These interventions created an opportunity of residence time for the water that could leave the area as overland flow to percolate and recharge the groundwater. Before the intervention the volume of runoff was estimated to be  $34967247.88 \text{ m}^3$  and while after different WHTs have been implemented the runoff volume is reduced to  $27547095.03 \text{ m}^3$ . Surface runoff generated from the upper bush land and bare land that has a total amount of  $7420152.85 \text{ m}^3$  is captured by the various physical conservation structures which are constructed at the foot hillsides of the catchment. The change of the volume of runoff is supposed to be percolated down and have augmented the groundwater. The rise of the water table from 15m to 3m deep below ground surface is evidence that the WHTs have such a great impact on groundwater recharge and thereby on the hydrology of the watershed.

## 7 Conclusion and Recommendations

In Abreha Weatsbeha farmers have detailed understanding of how conservation structures and vegetation in the upper part of the watersheds contribute to the amount of ground water discharge in the lower part of the catchment. The water discharged as a result of the aforementioned conservation and restoration activities is coined as a "water bank". After the implementation of integrated watershed management in the catchment, every drop of rainfall is supposed to be conserved either on the surface or underground. The intervention enhanced infiltration rate of the soil thereby reduced runoff that is generated from the different land uses. This leads to an increase in the depth of groundwater table up to three (3) meters below the ground surface. Since the intervention back in 1998, the groundwater table in the catchment has increased by 12meters. In light of this, there are now about 388 hand dug wells.

Currently, farmers are utilizing this water throughout the year either for complimentary or supplementary irrigation during dry spells in the rainy season. This result is achieved due to the strong commitment and extraordinary and exemplary leadership in the community.

The study area is characterized by high intensity and short duration convective type of rainfall falling during two months which can produce high surface runoff. As the annual total rainfall ranges between 350 to 600mm in the study area, the physical characteristics of the water harvesting interventions are found very effective in environmental rehabilitation, storing water and enhancing soil moisture. They also reduce erosion and flood risks to the downstream users and ultimately increase agricultural production. These effective structures employed in the catchment are classified into three implementing positions: 1) Recharging area where the slope of the catchment is high; 2) Intermediate area where the structures further allow to store floodwater and infiltrate into the soil and 3) Discharging areas where water is extracted and used for different purposes such as irrigation and domestic water supply (Fig. 2).

After the integrated watershed managements that have been practiced for 12 years (1998-2010), the land use land cover has shown dramatic changes and new land uses such as exclosures and irrigation lands are now introduced in hundreds of hectares. The change in the proportion of the degraded lands is impressive in that it has been reduced by 94.2%. The impact of the intervention is also very evident in boosting crop and horticultural production. It has also benefited livestock and honeybee production in the study area. The impact of the interventions on the hydrology of the catchment is also magnificent in that the overland flow from the catchment is reduced by 21.22%.

The study suggested that effective maintenance and design improvement of the physical water harvesting structures are continuously required. For better results and agricultural production, land suitability evaluation should be carried out before the implementation of different interventions. The soil is sandy and less fertile. Thus, the community eagerly needs area specific soil nutrient study for better fertilizer applications. Though there is enough potential of groundwater, the water demand for irrigation and other purposes with the existing water supply are found imbalance. Hence, deep boreholes together with electric motor pumps to lift the water to the command areas, needs to be implemented in the next few years.

Generally, the commitment and innovation of the local community is admirable and the change is so boldly visible that the watershed is now becoming a model in watershed management. However, in order to maintain the sustainability of the integrated watershed management, all stakeholders should give due attention to provide their shares. Despite numerous challenges (i.e., poor soil fertility, erratic rainfall, high erosion and degraded lands) in the study area, through integrated and community owned watershed management, climate change and drought resilient environment is now developed. Much of the households are also food secured. Finally, the saying in the community goes as “A man who has water has everything”. Today, everybody has enough resource for his/her life to improve its livelihood.

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