CHARACTERIZATION OF CLIMATE VARIABILITY AND WATER HARVESTING SYSTEM FOR CROP PRODUCTION IN ADULALA WATERSHED, CENTRAL RIFT VALLEY OF ETHIOPIA

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I hereby certify that I have read and evaluated this Thesis entitled 'Characterization of Climate Variability and Water Harvesting System for Crop Production in Adulala Watershed, Central Rift Valley of Ethiopia' prepared under my guidance by Moffat Goma. I recommend that it be accepted as fulfilling the thesis requirement.

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BIOGRAPHICAL SKETCH

The author was born in Chama District of Eastern Zambia from his father Auxensio Widson Goma and mother Dorothy Kanekwa Kaluba on May 4, 1983. He attended his primary school at Chama and Dungulungu Basic Schools respectively. He attended his secondary school at Kambombo and Lukulu secondary schools and later moved to Kambule Technical High School to complete his secondary education. He joined Natural Resources Development College (NRDC) in November 2001, and graduated in April 2005 with a diploma in Agricultural Engineering.

Right after graduation, he was employed as a Sales Engineer by Aquagro Limited and later joined the Ministry of Agriculture and Livestock as a Technical Officer under Land husbandry in 2006. In September 2008, he joined the then Bunda College of Agriculture a constituent college of the University of Malawi (now Lilongwe University of Agriculture and Natural Resources) to pursue his BSc. in Irrigation Engineering. Upon graduation in 2011, he was promoted to the position of District Irrigation Engineer. In October 2013, he joined the School of Graduate Studies of Hamaraya University to pursue his MSc. studies in Agrometeorology and Natural Risk Management.

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ACRONYMS AND ABBREVIATIONS

ADP	Area Development Programme
AWHC	Available Water Holding Capacity
BC	Before Christ
CRV	Central Rift Valley
CWR	Crop Water Requirement
EOS	End of the Season
FFW	Food for Work
FMAM	*Belg* (Short rainy season)
IRDPs	Integrated Rural Development Projects
JJAS	*Kiremt* (Main rainy season)
K	Potassium
KA	Kabele Administration
LGS	Length of Growing Season
MAX	Maximum
MIN	Minimum
NRD	Number of rain days
OM	Organic Matter
P	Phosphorus
RWH	Rainwater Harvesting
SOS	Start of the Season
TN	Total Nitrogen

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ABSTRACT

Scarcity of water is the most severe constraint for traditional agriculture in semi-arid areas of Ethiopia. Precipitation is extremely variable, thus water harvesting is crucial for ensuring improved crop production. A study was carried out to identify potential rainwater harvesting systems for improved crop production under climate variability in Adulala watershed, central rift valley of Ethiopia. Primary and secondary data together with other relevant information through a well-structured questionnaire were collected and analyzed to charachterize climate variability and water harvesting structures and to estimate runoff and crop water requirement. The inter annual rainfall variability showed a significant ($p<0.05$) increasing trend of 1.86 mm per year. The variability in the start of the season was non significant while increasing at a decreasing trend of 0.042 days per year. In the watershed, there are 38 water harvesting structures of which 34 are hemispherical and 4 are rectangular with storage capacity of about 90 and 320 m^3each respectively. The average monthly and annual surface runoff were found to be 3.05 and 36.6 mm respectively. The total irrigation volume required to supplement both major crops and vegetables per farmer was found to be 3285.9 $m^3$to cover 2 hectares .Considering the situation, additional storage structures for supplementary and full irrigation are necessary. Irrigation for small vegetables could be encouraged with the current storage volume and use of early maturing varieties should be considered under variable climate.

1. INTRODUCTION

Agriculture is at the nexus of three of the greatest challenges of the 21st century; achieving food security, adapting to climate change, and mitigating climate change while critical resources such as water, energy and land become increasingly scarce. Globally, extreme weather events and climate change will exacerbate the fragility of food production systems and the natural resource base particularly in environments prone to degradation and desertification, in areas of intense water stress, and wherever poverty undermines the capacity of rural people to take the needed preventive steps. (Beddington, *et al*., 2012).Thus, water harvesting is crucial for ensuring improved crop production and sustainable use of natural resources under climate variability.

Globally, rainwater harvesting is best known and practiced in the semi-arid areas where annual rainfall is in the range of 400 to 600 mm (Pacey and Cullis, 1986). Climate variability is likely to change rainfall patterns, resulting in shorter growing seasons in the future, particularly for subsistence farmers in Africa and parts of South Asia who rely on rain fed agriculture. According to FAO (2014), climate change and variability is a major challenge facing smallholder farmers and adaptation is now a priority in many countries of sub-Saharan Africa. This is particularly true in regions that already suffer from soil degradation, water scarcity and high exposure to climatic extremes, and where poverty and hunger persist. The Eastern African region (which includes Ethiopia, Kenya and Tanzania) is highly vulnerable to climate variability and several of its major sectors (notably agriculture) that significantly contribute to the sub-region’s economies are at risk. About 80 percent of the population in East Africa depends on agriculture, which contributes to 40 percent of the sub-region’s GDP. Climate change will significantly affect the agricultural sector in ways that without adaptation will ultimately reduce yields of subsistence crops, cash crops and the livestock sector.

In Ethiopia, over 90 percent of the food supply comes from rain fed small-holder agriculture, and rainfall failure means loss of major food supply which always results in massive food deficit. When this condition prevails consistently for two or more years, famine occurs (Getachew, 1999). The magnitude of rainfall variations in Ethiopia has been scaling up through time. As witnessed in several parts of the world, complications due to the amount and distribution of rainfall could be averted through the adoption and expansion of rainwater harvesting (RWH) practices.

According to UN officials, Ethiopia is among the nine countries of Africa which posses great potential for RWH. It is estimated that the country could meet the needs of six to seven times its current population, that is, equivalent to 520 million people (Daniel, 2007). The application of water harvesting technique however, although potentially high, is still low in Ethiopia.

According to Kedir and Shiratori (2006), in the Great Rift Valley (GRV) of Ethiopia such as Adama *Woreda* (District), the amount of rainfall and the duration of the rainy season are highly variable frequently resulting in low crop yields and associated low incomes. Characterized by erratic annual rainfall, frequent drought, crop failure, and lack of permanent water sources like streams and lakes, water harvesting technology is ideal in Adama. Except few *kabele* administrations (KAs) located along the course of Awash River, the rest totally depend on rainfall for crop production. "*Meher*" (that extends from June to September) is the main rainy season during which food crops are grown. Even during this main season of production, the occurrence of rainfall is unreliable. Late or early occurrence, uneven distribution, interruption and insufficiency of the rainfall are common in the area. Scanty showers that fall during "*belg*" season can only support some grass for livestock. Thus, overcoming the limitations of these arid and semi-arid areas and making good use of the vast agricultural potential under the Ethiopian context, RWH is a necessity rather than a choice. To this end, RWH is being introduced by the Area Development Programme (ADP) to counter the effects of the adverse natural conditions noted above and enhance food production through intensive backyard gardening using the water collected in the structures.

With the help of RWH, it is possible to make a more efficient use of rainfall water to improve agricultural production. This is achieved by collecting (harvesting) surface runoff from a large area and concentrating it on a smaller one. The target area can thus receive and store more water than the usual annual rainfall and crops can grow under more favorable soil moisture conditions.

Water harvesting is the collection of runoff for productive purposes. Instead of runoff being left to cause erosion, it is harvested and utilized. In the semi-arid drought-prone areas where it is already practiced, water harvesting is a directly productive form of soil and water conservation. Both yields and reliability of production can be significantly improved with this method (FAO, 1991).Water harvesting (RWH) can be considered as a rudimentary form of irrigation. Runoff can only be harvested when it rains. In regions where crops are entirely rain fed, a reduction of 50 percent in the seasonal rainfall, for example, may result in a total crop failure. If, however, the available rain can be concentrated on a smaller area reasonable yields will still be received. Of course in a year of severe drought there may be no runoff to collect, but an efficient water harvesting system will improve plant growth in the majority of years.

A successful development of rainwater harvesting systems require, first the identification of areas that are best suited for this technology. To identify such areas in a region or country, knowledge of climate, hydrology, vegetation, agricultural practices, soils, topography, socio-economic and infrastructure are required.

A number of rainwater harvesting structures have been implemented over the years in selected areas of Adulala watershed. Despite the existence of RWH structures in the watershed, water availability remains a major constraint to agriculture production thereby necessitating the need to identify systems that are appropriate in the watershed under climate variability.

Due to the aforementioned background, the objective of this study was to identify potential rainwater harvesting systems for improved crop production under climate variability in the study area under the following specific objectives:

- To characterize temporal variability of climate (rainfall and temperature).
- To characterize water harvesting structures in the watershed.
- To quantify runoff in the watershed
- To establish crop water requirements for major crops in the watershed.

2. LITERATURE REVIEW

2.1. History of Water Harvesting in Ethiopia

The first use of water harvesting techniques is believed to have originated in Iraq over 5000 years ago, in the so-called Fertile Crescent, which is believed to be the very cradle of agriculture. In both India and China, the technique was in use more than 4000 years ago (Falkenmark *et al*., 2001). The history of rainwater harvesting practiced in Ethiopia dates back as early as 560 BC, during the Axumite Kingdom. In those days, rainwater was harvested and stored in ponds for agriculture and water supply purposes, which are evidenced with documented literature and visual observations on the remains of ponds that were once used for irrigation during that period. Even these days, there are several traditional rainwater-harvesting technologies in Ethiopia, which have been used by communities in areas of water shortage. For many traditional communities in rural areas where natural sources of water are lacking, collection of rainwater from pits on rock outcrops and excavated ponds are common practices. In many semi-arid lowland areas of Ethiopia, where rainfall is not adequate for crop growth, farmers use runoff irrigation as a source of life-saving irrigation supplies (Meselech, 2014).

The promotion and application of rainwater harvesting techniques as alternative interventions to address water scarcity in Ethiopia was started through government initiated soil and water conservation programmes. It was started as a response to the 1971 to 1974 droughts with the introduction of food for work (FFW) programmes, which were intended to generate employment opportunities to the people affected by the drought (Meselech, 2014). The earlier rainwater harvesting activities included, among others, construction of ponds, micro-dams, bunds, and terraces in most drought-affected areas in Tigray, Wello and Hararghe regions (Kebede, 1995). Non-governmental organizations (NGOs) involved in Integrated Rural Development Projects (IRDPs) and the water sector in many parts of the country also undertake rainwater harvesting interventions. These interventions include conservation of rainwater by making use of physical structures and rainwater harvesting for domestic and irrigation purposes through pond and micro-dam construction and roof catchment schemes (Meselech, 2014).

2.2. Description of Water Harvesting

2.2.1. Definition and characteristics of water harvesting

More precisely, water harvesting can be defined as the process of concentrating rainfall as runoff from a larger catchment area to be used in a smaller target area. This process may occur naturally or artificially. The collected runoff water is either directly applied to an adjacent agricultural field (or plot) or stored in some type of on farm storage facility for domestic use and as a supplemental irrigation of crops. Water harvesting is generally feasible in areas with an average annual rainfall of at least 100 mm in winter rains and 250 mm in summer rains (Oweis *et al*., 1999).

Although the term water harvesting is used in different ways, the following are among its characteristics: (i) it is practiced in arid and semi-arid regions, where surface runoff often has an intermittent character (ii) it is based on the utilization of runoff and requires a runoff producing area and a runoff receiving area (iii) because of the intermittent nature of the runoff events, storage is an integral part of the water harvesting system. Water may be stored directly in the soil profile or in small reservoirs, tanks, and aquifers (Quraishi, 2014).

2.2.2. Classification of water harvesting techniques

FAO (1991), classified water harvesting into two broad categories as rainwater harvesting (local source) and flood water harvesting (channel flow). According to ATPS (2013), rain water harvesting techniques can be divided into two types depending on the source of water collected; namely, in-situ and the ex-situ types of rainwater harvesting respectively.

In-situ rainwater harvesting: In essence, in-situ rainwater harvesting technologies are soil management strategies that enhance rainfall infiltration and reduce surface runoff. The in-situ systems have a relatively small rainwater harvesting catchment typically not greater than 5 to 10 meters from point of water infiltration into the soil. The rainwater capture area is within the field where the crop is grown (or point of water infiltration). This technology often serves primarily to recharge soil water for crop and other vegetation growth in the landscape (FAO 1991). Malesu *et al*. (2006) argues that in-situ technique emphasizes on water management and conservation structures which are mostly traditionally considered for soil moisture conservation. This approach aims at maximum infiltration and minimum surface runoff to achieve better yields where soil moisture is a constraint.

Good soil water management in rain fed agriculture can also be achieved through minimum tillage and rainwater harvesting techniques/structures. Various researchers and development agencies such as Non-Governmental Organisations (NGOs) have explored *in-situ* rainwater harvesting. These include no till tied-ridging and mulch ripping (Mugabe, 2004). According to Morse (1996), mulch ripping has been explored as a soil water conservation technique. Trials conducted at Makoholi (1988–1993) indicated that mulch ripping outperformed other tillage methods such as tied ridging from the third season onwards. Mulch ripping gave higher soil moisture in the topsoil especially at the beginning of the cropping season and protected the soil from erosion and promoted infiltration. Land fallowing has been explored as a soil moisture conservation strategy. According to Nyamudeza and Maringa (1992), land fallowing as a soil moisture conservation practice depends on availability of land. Most smallholder farmers own 1-3 hectare pieces of land. For a farmer with limited land, the previously fallowed land should produce as twice as much grain to compensate for time when it has no crop. There are several in-field water conservation practices that have been used in several regions of Africa including: terraces, earth bunds, planting pits or planting basins and their modifications used in different parts of East and West Africa (Critchley, 2009).

Ex-situ rainwater harvesting: Hatibu (2003) defines the ex-situ technique as systems which have rainwater harvesting capture areas external to the point of water storage. The rainwater capture area varies from being a natural soil surface with a limited infiltration capacity, to an artificial surface with low or no infiltration capacity. Commonly used impermeable surfaces are rooftops that provide the platform to collect substantial amounts of water for different uses.

2.2.3. Main water harvesting techniques

Runoff may be harvested from roofs and ground surfaces as well as from intermittent or ephemeral watercourses. Water harvesting techniques which harvest runoff from roofs or ground surfaces fall under the term ‘‘rainwater harvesting” while all systems which collect discharges from watercourses are grouped under the term “floodwater harvesting” (FAO, 1991).

As the storage systems of ex-situ systems often are wells, dams, ponds or cisterns, water can be abstracted easily for multiple uses including irrigation or domestic, public and commercial uses through centralized or decentralized distribution systems.

Ponds: Traditional ponds have been used in Ethiopia for millennium; some estimates it as early as 560 BC (Fattovich, 1990). They are used to harvest rainwater for both human and livestock watering, particularly in the arid and semi arid rural areas where annual rainfall is less than 700 millimeters. They are major sources of water in the rift valley where ground water is deep and other sources of water are not feasible. Ponds are simple to construct and the community can manage it. The most common type of pond is the excavated type. The size of the ponds range from 650m^3 to several thousands, and they serve for 3 to 6 months and largely during the rainy season (Getachew, 2003).

Dug Wells: Dug Wells (3 to 15 meters) are major sources of water both for domestic water supply and agricultural use and are widely used in wetland areas, sand river beds and valley bottom lands in the Ethiopian highlands. Their potential at times is very low and get dry during the driest period of the year; March to April. Shallow wells equipped with a 200 liter barrel and small scale drip irrigation on approximately 0.1 hectares support the production of high value crops (BOA, 2002).

Elas: Elas are other types of traditional wells (5 to 10 meters) widely used for livestock watering in Borena, Southern Ethiopia. Water is lifted through a human chain lined up along the wall of the well each standing on a terrace like structure, and the lifting of water is continuous using two or more containers at one time; one container going up with water, the empty one down. A three to five meters livestock-watering trough extends near the edge of the well and lifted water is emptied into the trough (Getachew, 2003).

Underground Cistern (China Type): A Chinese designed underground cistern for runoff storage is now being introduced for farmers in drought prone areas in Ethiopia. The underground cistern is of two types, the first type is a closed system having a bottle shape, and the second type is a half circular or hemispherical. The first type cistern is made from reinforced concrete, and it is circular in shape, 100 to 120 centimeters diameter circular at the top, and bulges out immediately at a depth of 300 centimeters depth (neck of the structure), and the diameter increase to 380 to 400 centimeters, and the total height of the structure is 780 centimeters. The structure is built using the soil first curved out (mold) in the shape of the cistern. The existing experience is that it may be a bit difficult to construct by the farmer, and it is also expensive (Getachew, 2003).

However, storage systems for supplemental irrigation are less common, especially in Sub Sahara Africa (Falkenmark *et al.*, 2001). Kihara (2002) reported that a study of RWH in four Greater Horn Africa (GHA) countries (i.e. Ethiopia, Kenya, Tanzania and Uganda) revealed that, despite the relatively high investment costs compared to in situ systems, RWH for supplemental irrigation is slowly being adopted with high degree of success. In this system, surface runoff from small catchments (1-2 ha) or adjacent road runoff is collected and stored in manually and/or mechanically dug farm ponds (50-1000 m^3 storage capacity). Due to the low volumes of water stored compared with crop water requirements, improved benefits of these systems are derived by incorporating efficient water application methods such as low pressure (0.5-1.5 m) drip irrigation (Ngigi *et al.*, 2000; Ngigi, 2001).

2.3. The Role of Water Harvesting in Agriculture

According to Intergovernmental Panel on Climate Change (IPCC, 2013), the warming of the climate system is unequivocal; many of the observed changes since the 1950s such as increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level are unprecedented over decades to millennia. In

Ethiopia, there has been a warming trend in the annual minimum temperature over the past 55 years, increasing by about 0.37°C every ten years (NMA, 2007). Rainwater harvesting helps to reduce vulnerability of communities arising from the shortage of water induced by temporary or permanent changes in the climate and or the depletion of the water resources. Small holder rainwater harvesting based agriculture can play a significant role in improving the nutrition status of both rural and urban residents through the transformation of the cropping patterns (Yohannes, 2014). Rainwater harvesting can improve the productivity of agriculture in areas that suffer from climate variabilities, helping them to contribute more to national development beyond fulfilling their own needs. Water harvesting has an important role to play in poverty reduction, sustainable development and adaptation to climate variability (McCartney and Smakhtin, 2010). For example, Pandey *et al.* (2003), documented over a hundred instances of rainwater harvesting based adaptation to climate variability in India during the Holocene.

According to Mwangi (1998), water harvesting has the capacity to improve food security, income levels and the standards of living of people living in dry areas. This is possible through the following:

i). Conservation of soil and water resource base; runoff from land is one of the most erosive forms of water, leaving the land with rills and gullies. This runoff can be held on the soil surface and encouraged to infiltrate.

ii). Improving overall crop yield; WH is used to divert, hold and control the movement of runoff water, thereby increase water supply and retention, crop yields and thus food security can be improved significantly.

iii). Improved tree seedling survival and growth rate; the most critical aspect of tree establishment in dry areas is soil moisture supply. Reports from experiment in dry areas indicate that a high seedling survival rates can be achieved if moisture supply can be improved.

Moreover, the improvement of husbandry practices is essential for successful water harvesting technology and these include;

a). Fertility improvement by use of inorganic and organic fertilizers.

b). Return of crop residues to maintain and improve organic matter content.

c). Suitable crop rotations with legumes, cereals and deep rooted trees.

2.4. Soil Requirements for Water Harvesting

The physical, chemical and biological properties of the soil affect the yield response of plants to extract moisture harvested. Generally the soil characteristics for water harvesting should be the same as those for irrigation. Ideally the soil in the catchment area should have a high runoff coefficient while the soil in the cultivated area should be a deep, fertile loam. Where conditions for cultivated and catchment areas conflict, the requirements of the cultivated area should always take precedence (FAO, 1991).

The most important characteristics of potential areas for runoff irrigation are texture, structure, depth, fertility, salinity/sodicity, infiltration rate, available water holding capacity, constructional characteristics of the soil, acidity or alkalinity (FAO, 1991).

2.4.1. Texture

The texture of a soil has an influence on several important soil characteristics including infiltration rate and available water capacity. Soil texture refers to its composition in terms of mineral particles. A broad classification include; coarse textured soils which are sand predominant ‘‘sandy soils’’, medium textured soils which are silt predominant "loamy soils"and fine textured soils which are clay predominant "clayey soils" Generally, it is the medium textured soils, the loams, which are best suited to WH system since these are ideally suited for plant growth in terms of nutrient supply, biological activity and nutrient and water holding capacities (BTSM, 1991).

Furthermore, Salazar and Casanova (2010), in their study of RWH revealed that the relevant parameter in terms of the soil is the texture. Soils that develop a crust on the surface as a result of the impact of raindrops may be more suitable for runoff areas, while fine-textured soils, which can store more water than coarse-textured soils, may be more preferable for basin areas. In a macrocatchment water harvesting experiment in Pakistan, Khan *et al*. (2009) studied how different soil texture (silty clay, clay loam, silty clay loam, silt loam and loam) in the basin area affected the grain and straw yield of a wheat crop. They found that the highest wheat grain and straw yields were obtained from loam soils and the lowest from silty clay soils as a result of relatively heavy rainfall in the months prior to harvest of the wheat crop.

2.4.2. Depth

The depth of soil is particularly important where WH systems are proposed. Deep soils have the capacity to store the harvested runoff as well as providing a greater amount of total nutrients for plant growth. Soils of less than one meter deep are poorly suited to water harvesting. Two meters depth or more is ideal, though rarely found in practice (FAO, 1991). However, in the case of in- situ RWH studies have shown that the capacity of the harvested water stored in the soil of the cultivated area depends on the number and size of the soil pores (texture) and the soil depth. The available water storage capacity is expressed in mm water depth (of stored water) per meter of soil depth, mm/m. (Anschütz *et al*., 2003).

2.4.3. Fertility

In many of the areas where WH systems may be introduced, lack of moisture and low soil fertility are the major constraints to plant growth. Some areas in Sub-Saharan Africa, for example, may be limited by low soil fertility as much as by lack of moisture. Nitrogen and phosphorus are usually the elements most deficient in these soils. While it is often not possible to avoid poor soils in areas under WH system development, attention should be given to the maintenance of fertility levels (Olsen and Dean, 1965). For instance, studies in Kenya have indicated that low soil fertility and moisture deficits are major constraints to crop production in the semi-arid areas of Kenya and that farmers need to augment the limited quantities of farmyard manures available on smallholder farms with inorganic fertilizers and combining with appropriate water harvesting techniques for increasing the yields (Gichangi, *et al*., 2007).

2.4.4. Salinity/ sodicity

Sodic soils, which have a high exchangeable sodium percentage and saline soil which have excess soluble salts, should be avoided for WH systems. These soils can reduce moisture availability directly, or indirectly, as well as exerting direct harmful influence on plant growth (FAO, 1991).

Qadir and Oster (2003) reports that a variety of plant species of agricultural significance have been found to be effective in sustainable reclamation of calcareous and moderately sodic and saline-sodic soils through a vegetative bioremediation (a plant-assisted reclamation approach) which relies on growing appropriate plant species that can tolerate ambient soil salinity and sodicity levels during reclamation of salt-affected soils. The second strategy fosters dedicating soils to crop production systems where saline and/or sodic waters predominate and their disposal options are limited.

2.4.5. Infiltration rate

The infiltration rate of a soil depends primarily on its texture. A very low infiltration rate can be detrimental to WH systems because of the possibility of water logging in the cultivated area. On the other hand, a low infiltration rate leads to high runoff, which is desirable for the catchment area. The soils of the cropped area however should be sufficiently permeable to allow adequate moisture to the crop root zone without causing water logging problems. The requirements of the cultivated area should always take precedence (FAO, 1991). Furthermore, Khan *et al*., (2009) report that a number of studies have evaluated the use of plastic covers and the application of soil amendments, dispersants and sealing materials to reduce infiltration and increase runoff in runoff areas. For instance, Ben-Hur (1991) evaluated the effects of application of polymetaphosphate (NaPMP) and sodium tripolyphosphate (STP) on seal formation and runoff rate and found that dispersant agents weakened the stability of the soil aggregates, increased clay dispersion and enhanced seal formation, with NaPMP being more efficient than STP in increasing runoff.

2.4.6. Available water holding capacity

The capacity of soils to hold, and to release adequate levels of moisture to plants is vital in water harvesting. AWHC is a measure of this parameter, and is expressed as the depth of water in millimeters readily available to plants after a soil has been thoroughly wetted to "field capacity". Not only is the AWHC important, but the depth of the soil is critical also. In WH systems which pond runoff, it is vital that this water can be held by the soil and made available to the plants (Baurah and Barthakur, 1997). Furthermore, on-farm research in semi-arid locations in Kenya (Machakos district) and Burkina Faso (Ouagouya) during 1998-2000 (Barron *et al*., 1999; Fox and Rockstrom, 2000) indicates a significant scope to improve water productivity in rain fed agriculture through supplemental irrigation, especially if combined with soil fertility management. The results were more promising on soils with higher water holding capacity on which crops seem to cope better with intra-seasonal dry spells.

2.4.7. Constructional characteristics

The ability of a soil to form resilient earth bunds (where these are a component of the WH system) is very important, and often overlooked. Generally the soils which should particularly be avoided are those which crack on drying, namely those which contain a high proportion of montmorillonite clay (especially vertisols or "black cotton soils"), and those which form erodible bunds, namely very fine sandy soils, or soils with very poor structure (FAO, 1991).

2.4.8. Acidity and alkalinity

What makes a soil fertile or infertile are the many complex chemical processes and exchanges that take place in soils and plant systems. The general nature of the soil departs from the chemical neutrality either acidity or alkalinity (baseness).

Soil acidity or alkalinity is important since it determines the availability of nutrients to plants and ultimately controls plant growth. A plant is unable to absorb nutrients unless they are dissolved in liquid. However, when the soil moisture lacks some degree of acidity, the soil water has little ability to dissolve minerals and release their nutrients. As a result, even though the nutrients are in the soil, plants may not have access to them. Water harvesting can correct this alkalinity under good drainage. A strongly acid soil is also detrimental to plant growth. In such acidic soil, the soil moisture dissolves nutrients, which become leached away before they can be obtained by plant roots. Luckily, it can be corrected by the addition of lime to the soil. (FAO, 1991)

The acidity or alkalinity of a soil is measured on a scale of 0 to 14 called the pH scale. This actually is the measure of the hydrogen ions present in the moisture. Low pH indicates acidity conditions. Soil scientists have shown that most complex plants will grow only in soils whose pH is between 1- 10. Nevertheless, the optimum pH for plant productivity varies with plant itself. Like plants the microorganisms are highly sensitive to soil pH and each has its own optimum situation (FAO, 1979a).

However, Singh *et al*. (2012), reported that a study conducted on the effect of rainwater harvesting and afforestation on soil properties in western India revealed an increase in soil organic carbon while soil pH and electrical conductivity reduced and concluded that RWH and afforestation facilitated soil improvement.

2.5. Major Components of Rainwater Harvesting Systems

There are a multitude of techniques potentially feasible for use in water harvesting systems. Irrespective of the technique used to collect and store the water or the ultimate use of the water, all water harvesting systems have the following components.

2.5.1. Catchment area

It is an area where rainwater is concentrated and runs off the target area. The catchment area can be as small as a few square meters or as large as several square kilometers. It can be agricultural, rocky or marginal land, or even a rooftop or a paved road. The rainwater harvested from catchment area should be proportional to command land. To increase the volume of runoff there are three catchment treatment methods: topography modification, soil modification, and impermeable coverings.

2.5.2. Runoff delivery systems

In order to convey runoff from the catchment to the storage, some sort of delivery system is normally required. The diversion channel leading runoff from the ground catchment area to the silt trap and into the tank should be made of compacted earth, or lined with cement or other materials. Depressions or primary sediment pits are used for ground catchment delivery systems to settle sediment as much as possible before entering silt trap. If the catchment area is a roof top, a gutter and flush guard are fixed to carry water from the roof into the tank (Gould and Petersen, 1999).

2.5.3. Silt trap or sediment pond

It is used to allow the sediment which is being carried in the runoff from the catchment area to settle. Its size is determined according to sediment characteristics and flow discharge. If a lot of sediment is expected, a two-chamber silt trap is recommended one chamber to catch sand, and the second one to trap finer material. A filter mesh is used to trap leaves, twigs and other debris before the water drains into the tank. It is dug at least 3 meters away from the storage tank to prevent water from over topping during heavy rains and damaging the tank (MOA, 2002). Experience in China shows that the appropriate shape of sediment pond is rectangular with depths of 0.6 to 0.8 meters, length (L) to width (B) ratio of 2:1. Under Ethiopian condition, the recommended size of silt trap is 100 centimeters deep, 250 centimeters long and 100 to 150 centimeters wide. The compartment is made at a distance of 150 centimeters from the inlet and the spillway is made on the compartment at 30 centimeters depth and 40 centimeters width. The size of the channel connecting the catchment to the silt trap is kept as 20 centimeters deep and 40 centimeters wide. The outlet from the silt trap to the storage tank is made using 10 to 15 centimeters pipe depending upon discharge and laid at a depth of 40 centimeters and a filter is provided at the mouth of the outlet (BOA, 2003).

2.5.4. Storage facility

It is the place where runoff water is stored from the time it is collected until it is used. Different size and shape of surface and sub surface storage structures are available.

Storage tanks and ponds are the common ones. Storage tanks can be above ground, which are common in the case of roof catchment systems or underground tanks, which are normally associated with ground catchment systems. The type of storage selected for use as rainwater harvesting structure depends on many factors such as the ultimate use of the water, cost, availability of construction materials, availability and skill of labor, and the site topography (Pacey and Cullis, 1986).

The choice of suitable and cost effective rainwater harvesting tank having appropriate volume needs careful consideration of the existing catchment area, rainfall conditions and the amount of water required. Field experience has shown that universally ideal rainwater harvesting tank design does not exist. Local materials, skill and costs, personal preference and other external factors may favor one design over another (Gould and Petersen, 1999). In many rainwater harvesting systems the water storage facility is the most expensive single item and may represent in excess of 50 percent of the total cost of the entire system (Kihara, 2002). Unlined earthen tanks or ponds are usually not a satisfactory structure for water storage unless seepage losses can be controlled. In some installations, lining with plastic sheets or soil sealed with concrete or any other suitable materials can control seepage. A better and cheaper solution to water proofing is a material called Nil which is made by mixing cement with water to form a thin paste (cement slurry) and it is applied to the final layer of a plaster (Gould and Petersen, 1999). Controlling water lost by evaporation is one of the most effective methods of maintaining adequate water storage and should be an integral part of any open water storage facility (Arega, 2003). In tropical and hot arid climates, water tanks should be white-washed or lined with white color material to make it more reflective and reduce the effect of solar heating (Gould and Petersen, 1999). Although relatively expensive, a roof over the rainwater storage facility is an effective means of controlling evaporation (Hune and Kimeu, 2002) and reduces the risk of contamination by preventing insects and small animals entering the storage (Gould and Petersen, 1999).

Common shapes of storage tanks or cisterns constructed in Ethiopia are hemispherical, dome, cylindrical, bottle shape, trapezoidal, rectangular and cone- shaped (BOA, 2002).

Lining materials used are Ferro-cement and polythene sheeting to check seepage loss and roofing with local materials or plastic sheets to reduce evaporation loss is recommended (BOA, 2003). The capacity of the tanks usually varies from 10 to 60 cubic meters. Storage tanks are constructed in excavation with the soil being backfilled around the outside of the tank on completion. Where the soil is firm, some of the forces of the water against the side of the tank are absorbed by the soil and the walls do not have to be as strong as equivalent surface tank. For Ferro-cement tanks, it is possible to line a carefully excavated hole with chicken wire reinforcement and plaster directly on it. Before the construction starts, proper site for placing of tanks need to carefully be selected with respect to the possible damaging effect of soil erosion since surface runoff can undermine the foundations of the tank. If such sites have to be used, bunds and/ or cutoff drains should be constructed to divert flood water away from the base of the tank (Gould and Petersen, 1999).

The common shapes of local ponds are circular and trapezoidal. A farm pond essentially consists of inlet, storage area, and earthen embankment and spillway (Arega, 2003). Since it is earthen pond seepage losses is relatively high. The design should consider all losses and proper treatment should be applied to minimize the losses (Landell, 2004).

2.5.5. Discharge channel (pipe) or spillway

Discharge channel (pipe) or spillway is an integral part of the storage pond/tank to ensure that over topping of the embankment is avoided and excess flood flows disposed off safely from storage. It is normally placed at the highest design water level of the storage (Gould and Petersen, 1999). The pipe can be of PVC, concrete or other materials with the diameter of not less than 10 centimeters or an open channel. An alternative way of diverting excessive water when water level in the storage comes up to the design storage level is to block the inlet and to divert runoff to some other area sufficiently away from storage (BOA, 2003) .

2.5.6. Command area

The size of the command area depends upon the amount of water harvested from the runoff area and the water requirement for different uses. Many water harvesting systems are established merely by estimating the ratio of catchment and command area (BOA, 2002).

2.6. Design Principles of Rainwater Harvesting

The design principles of rainwater harvesting systems are similar to those of other hydraulic structures involving many parameters (Arega, 2003). They are usually constructed by the local rural population without expert guidance using hand labor. Under these circumstances it will be difficult to apply hydrological models. Moreover, it is difficult to estimate flood discharge, volume, duration and peak due to lack of hydrological information data. The basic criterion for planning rainwater harvesting systems is the catchment/command area ratio (FAO, 1994). This area ratio is specific to each region and depends on the rainfall probability patterns and on crop water requirements. Where this ratio is known or assumed, the possible size of the command area to be irrigated can easily be determined. The size of the catchment area can be measured or estimated. Then, the area ratio becomes the basic tool for the design, integrating the effects of runoff coefficient, rainfall characteristics, soil, and crop factors.

Design rainfall is the total amount of rainfall during the cropping season at which or above which the catchment area will provide sufficient runoff to satisfy the crop water requirement. It is usually assigned with a 67 percent probability of exceedance (Pruit, 1990). Crop water requirement can be calculated using CROPWAT computer programme (FAO, 1998) and the difference between crop water requirement and effective rainfall is an irrigation requirement. Runoff coefficient of a catchment is the ratio of runoff volume to rainfall volume.

Water demand (water requirement): It is important to account for water losses during the storage by seepage and/or evaporation and during distribution and application of water. In the design of rainwater harvesting systems in Ethiopia a loss of 20 percent (as efficiency factor) of the demand is considered. In addition to irrigation water requirement, drinking water for livestock and humans is considered in some areas. The length of the dry season will determine the size of the storage tank or pond. Water demand in general is the sum of irrigation water requirement, domestic water requirement and losses (Marco and Hune, 2000).

Design harvested water: The amount of runoff water harvested from the catchment area is a function of the amount of runoff created by rainfall in the catchment area. The amount of runoff depends on rainfall characteristics (intensity, amount and duration), antecedent soil moisture, soil type, physical characteristics of the catchment (shape, area and slope), ground cover and agricultural practices (FAO, 1994).

2.7. Rainfall - Runoff Analysis for Rainwater Harvesting

Runoff is generated by rainstorms and its occurrence and quantity are dependent on the characteristics of the rainfall event, i.e. intensity, duration and distribution, soil type, vegetation, slope and catchment size. Precipitation in arid and semi-arid zones results largely from convective cloud mechanisms producing storms typically of short duration, relatively high intensity and limited areal extent (FAO, 1991). For a water harvesting planner, the most difficult task is therefore to select the appropriate "design" rainfall according to which the ratio of catchment to cultivated area will be determined.

Design rainfall is defined as the total amount of rain during the cropping season at which or above which the catchment area will provide sufficient runoff to satisfy the crop water requirements. If the actual rainfall in the cropping season is below the design rainfall, there will be moisture stress in the plants; if the actual rainfall exceeds the design rainfall, there will be surplus runoff which may result in damage to the structures.

The design rainfall is usually assigned to a certain probability of occurrence or exceedance. If for example, the design rainfall with a 67 percent probability of exceedance is selected, this means that on average this value will be reached or exceeded in two years out of three and therefore the crop water requirements would also be met in two years out of three. The design rainfall is determined by means of a statistical probability analysis (FAO, 1992).

2.7.1 Probability analysis

For the design of water harvesting schemes, this method is as valid as any analytical method described in statistical textbooks.

The first step is to obtain annual rainfall totals for the cropping season from the area of concern. In locations where rainfall records do not exist, figures from stations nearby may be used with caution. It is important to obtain long-term records. The variability of rainfall in arid and semi-arid areas is considerable. An analysis of only 5 or 6 years of observations is inadequate as these 5 or 6 values may belong to a particularly dry or wet period and hence may not be representative for the long term rainfall pattern (FA0, 1991).

The design rainfall in case of irrigation is the dependable rainfall at 80 percent probability of exceedance (FAO, 1992). The amount of rainfall which occurs 1 out of 5 years corresponding to 80 percent probability of exceedance and representing a dry year. 80 percent probability of exceedance, characterizing a dry year with rainfall in 4 out of 5 years exceeding is used as criteria determining water availability (FAO, 1992).

Plotting the ranked observations against the corresponding probabilities on normal probability paper, and from the curve fitted to the plotted observations, it is possible to obtain the probability of occurrence or exceedance of rainfall value of a specific magnitude. Inversely, it is also possible to obtain the magnitude of the rain corresponding to a given probability.

2.7.2. Climate variability

Water harvesting planning and management in arid and semi-arid zones present difficulties which are due less to the limited amount of rainfall than to the inherent degree of variability associated with it. In arid and semi-arid climates the ratio of maximum to minimum annual amounts is much greater and the annual rainfall distribution becomes increasingly skewed with increasing aridity. With mean annual rainfall of 200 to 300 millimeters the rainfall in 19 years out of 20 typically ranges from 40 to 200 percent of the mean and for 100 millimeters/year, 30 to 350 percent of the mean. At more arid locations it is not uncommon to experience several consecutive years with no rainfall (FAO, 1992).

According to NMSA (1996), Ethiopia has one of the most variable rainfall patterns that form a natural part of farming in the world. A number of professionals and organizations have documented scientifically interesting reports on Ethiopian rainfall variability through classifying the country into various and wider temporal and spatial rainfall categories. Mesay (2006) reported that the first attempt of producing onset and cessation of the small and the main rainy season of Ethiopia were made by Mr. Tesfaye Haile in 1989 E.C on pentad basis. In the work, cumulative curve approach integrated with running mean and direct statistical analysis were applied to determine the time of onset and cessation of the rains. Haile (1986) also reported that drought occurs every 3-4 years in the northern and 6-8 years in other parts of Ethiopia. Furthermore, according to Girma (2005), such a pronounced inter-annual and seasonal rainfall variability as well as extreme events, production risks and stresses to which the farming systems are exposed can arise from a wide variety of sources. Evidences indicate that daily records of the past rainfall episodes can be examined and combined effectively so as to eventually reveal certain useful pattern pertaining to farm level strategic and tactical decision making. Therefore, determining the possible ranges of rainfall onset date (SOS), end date (EOS), duration (LGS) , seasonal totals and dry spell length, which together make up the overall rainfall features, can provide deep insight into translation of the ‘rainfall variability’ into the field level management options through proactive responses. According to Stern *et al.* (1982), the start of the rainy season is defined as the first occurrence of at least ‘X’ mm rainfall totaled over‘t’ consecutive days. This potential start can be a false start if an event, F, occurs afterwards, where F is defined as a dry spell of ‘n’ or more days in the next ‘m’ days. Various authors have used similar criteria in assessing the SOS (Barron *et al.*, 2003; Girma, 2005; Mesay, 2006; Kassie *et al.*, 2013).

Several methods are in use to determine the onset, cessation, and the length of growing season. Some of these methods involve:

1. Rainfall amount and the number of rainy days (Raes *et al*., 2004; Segele and Lamb, 2005).
2. Percentage cumulative mean rainfall, with and without considering the number of rainy days (Odekunle, 2006).
3. Cumulative rainfall anomalies (i.e., departures from the long-term mean) (Camberlin *et al*., 2009).
4. Rainfall evapotranspiration relation (Edoga, 2007); Mawunya *et al*., 2011).

2.7.3. Factor affecting runoff

Apart from rainfall characteristics such as intensity, duration and distribution, there are a number of site (or catchment) specific factors which have a direct bearing on the occurrence and volume of runoff.

Soil type: The infiltration capacity is among others dependent on the porosity of a soil which determines the water storage capacity and affects the resistance of water to flow into deeper layers. Porosity differs from one soil type to the other. The highest infiltration capacities are observed in loose, sandy soils while heavy clay or loamy soils have considerable smaller infiltration capacities. The infiltration capacity depends furthermore on the moisture content prevailing in a soil at the onset of a rainstorm. The initial high capacity decreases with time (provided the rain does not stop) until it reaches a constant value as the soil profile becomes saturated (Finkle and Seerggeros, 1995).

Vegetation: The amount of rain lost to interception storage on the foliage depends on the kind of vegetation and its growth stage. More significant is the effect the vegetation has on the infiltration capacity of the soil. A dense vegetation cover shields the soil from the raindrop impact and reduces the crusting effect as described earlier.

In addition, the root system as well as organic matter in the soil increases the soil porosity thus allowing more water to infiltrate. Vegetation also retards the surface flow particularly on gentle slopes, giving the water more time to infiltrate and to evaporate (Finkle and Seerggeros, 1995).

Slope and catchment size: Investigations on experimental runoff plots have shown that steep slope plots yield more runoff than those with gentle slopes. In addition, it was observed that the quantity of runoff decreased with increasing slope length to some extent (Ben *et al*., 1988).

The runoff efficiency (volume of runoff per unit of area) increases with the decreasing size of the catchment i.e. the larger the size of the catchment the larger the time of concentration and the smaller the runoff efficiency (Ben *et al*., 1988).

2.7.4. The US soil conservation service (SCS) method

The SCS Curve Number method (CN method) was developed from many years of storm data by the USDA Soil Conservation Services. It is used to estimate runoff volume on large agricultural watershed. The curve number method has found worldwide application throughout the entire spectrum of hydrology, and it is one of the most common means of determining runoff quantities in unmonitored catchment areas (Rallison, 1980; Rallison and Miller, 1982).

The SCS curve number estimates the direct runoff (depth) or rainfall excess storm wise. This method is based on the potential maximum retention (S) of the watershed, which is determined by wetness of the watershed.

2.8. Crop Water Requirement

For the design of water harvesting systems, it is necessary to assess the water requirement of the crop intended to be grown. From ascertaining water requirements, the amount of evapotranspiration of the crop must be determined from the crop coefficient K_c and reference evapotranspiration, a value that depends on the growing period of the crop and the climate (Doorenbose and Pruit, 1977).

The water requirement and the effective root zone at the time of the greatest water requirement during flowering and fruiting phases serves as the basis for assessing the minimum amount of soil moisture required by plants growing without contact with groundwater (Tauer and Hamburg, 1992).

The reference crop evapotranspiration ET_o is defined as the rate of evapotranspiration from a large area covered by green grass which grows actively completely shades the ground and which is not short of water. The rate of water that evaporates and transpires depends on climate. The highest value of ET_o is found in areas that are hot, dry, windy and sunny. In many cases it will be possible to obtain estimates of ET_o for the area of concern (or an area nearby with similar climatic conditions) from the meteorological service (FAO, 1992; Allen *et al*., 1998). Reference evapotranspiration expresses the evaporating power of the atmosphere at a specific location and time of the year independent of crop type, crop development and management practices. As water is abundantly available at the reference evapotranspiring surface, soil factors do not affect ET_o. Although several methods exist to determine ET_o, the Penman Montieth method has been recommended as the appropriate combination method to determine ET_o from climatic data on: Temperature, Humidity, Sunshine and Wind speed (Abdalla *et al*., 2008). However, the CROPWAT model is widely used to estimation of ET_o and ET_c.

CROPWAT is a computer programme for irrigation planning and management, developed by Land and Water Development Division FAO (Smith, 2001). Its basic function includes the calculation of reference evapotranspiration, crop water requirement and scheme irrigation requirement. Through a daily water balance, the user can estimate yield reduction, irrigation and rainfall effectiveness. Typical application of the water balance includes the development of irrigation schedule for various irrigation methods, the evaluation of irrigation practices as well as rain fed production and drought effects.

Calculation of crop water and irrigation water requirements utilizes input of climatic (air temperature, relative humidity, wind speed and sunshine hours), crop and soil data, as well as crop coefficient and rainfall data. (FAO, 2000). Reference evapotranspiration is obtained from climatic data in the FAO penman Monteith method (Allen *et al*., 1988).

3.0. MATERIALS AND METHODS

3.1. General Description of the Study Area

Adulala Watershed is located about 104 km south-east of the capital, Addis Ababa in the Central Rift Valley (CRV) of Ethiopia in East Shoa Zone and geographically situated between 8° 26.5' to 8° 29.5' N and 39° 17' to 39° 20.5' E at an altitude range of 1,657 to 1,688 m a.s.l and covers an area of 2,747.7 hectares (Figure 1). The Watershed has 923 households and a population of 4722.

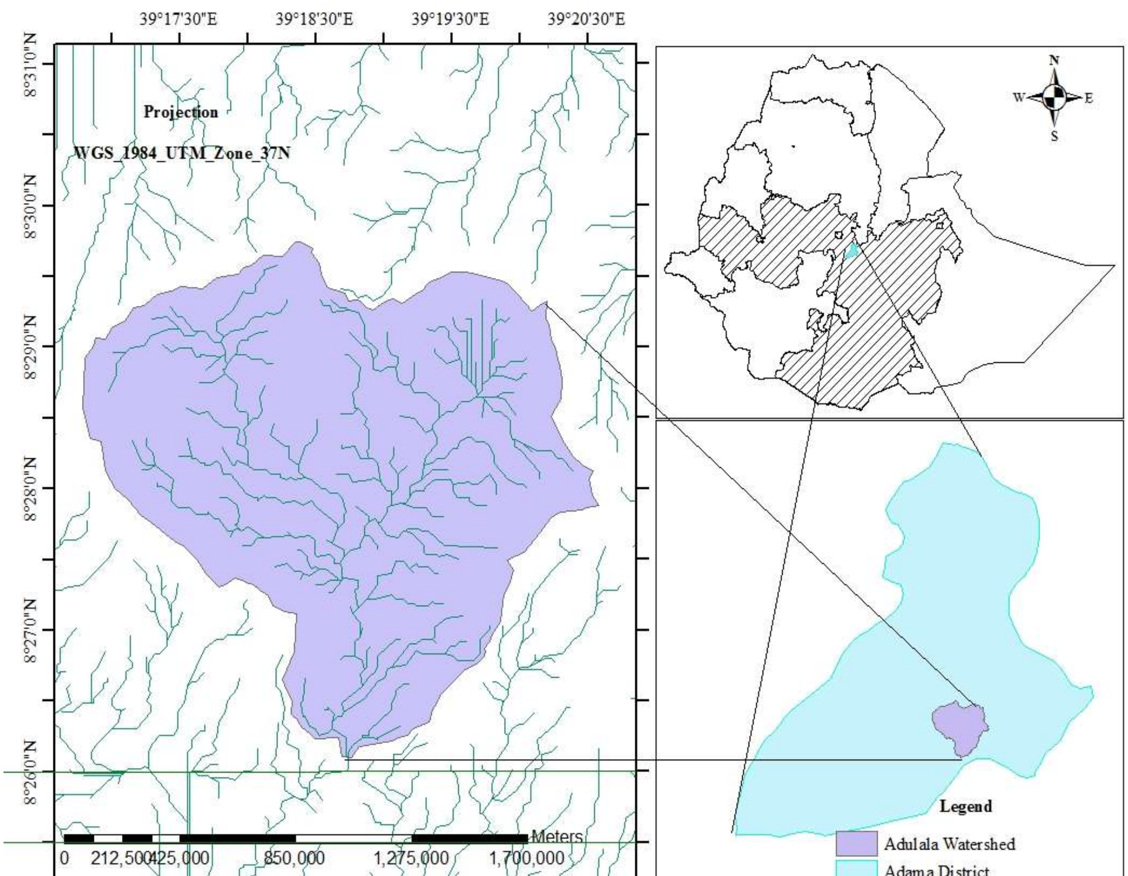

Figure 1: Location map for Adulala Watershed.

3.1.1. Climate

The climate is semi-arid and the long-term (1977 – 2013) average rainfall is about 820 millimeters per year (Figure 2). The short rains come in February to May, while the long rains come from June to September. From the long-term climatic data, the Watershed is characterized by a maximum annual mean temperature of 28.5°C and a minimum annual mean temperature of 13.87°C (Figure 2).

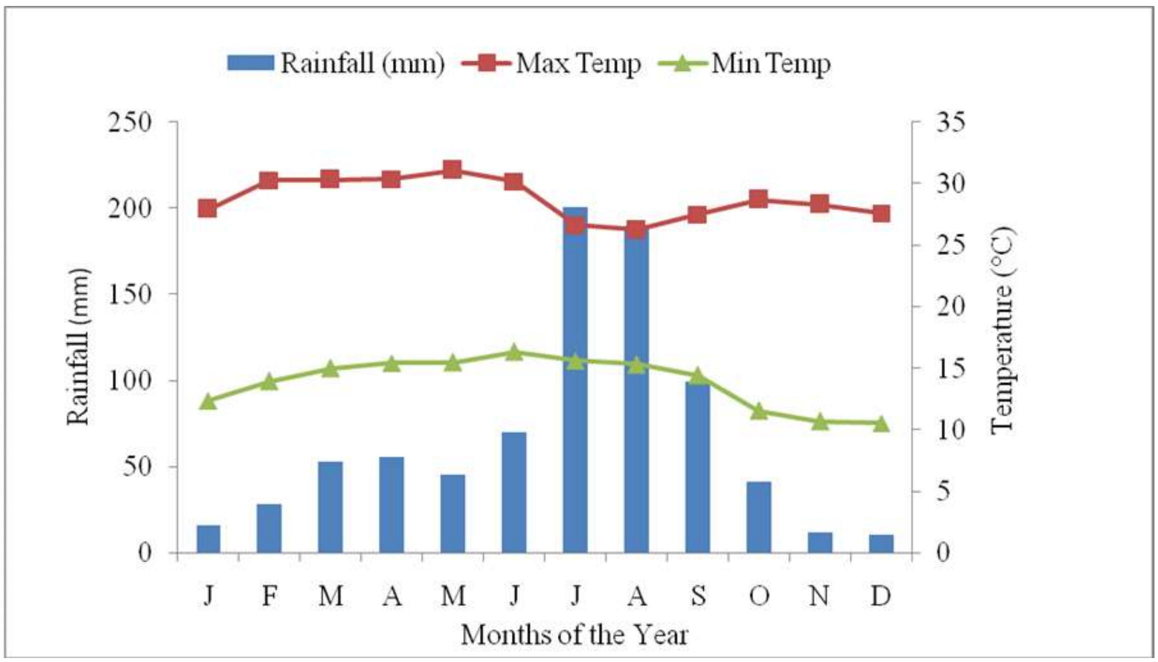

Figure 2: Mean annual rainfall and mean maximum and minimum temperature for Adulala watershed (1977 - 2013).

3.1.2. Topography

The Watershed is comprised of diversified topographic features such as undulating to rolling plains and flat plains with substantial proportion of low to moderate relief hills. The soil types are generally dominated by Fluvisols (medium textured soils). The textural classes of the soils are sandy loam and loam soils.

3.1.3. Farming practices

Different farming practices such as tie ridges, terracing, water harvesting, irrigation, conservation farming, mulching, compost, animal manure and improved varieties are practiced in the Watershed. Farmers have cattle, donkey, goat, sheep and chicken (local and cross bred). The average land holding in Adulala watershed is 1.75 hectares. The land is almost one hundred percent (100%) cultivated and only 0.11 ha become fallow.

Agricultural constraints in the watershed include; pest and diseases, high cost of input and high climate variability, lack of grazing land and low water availability.

3.2. Household Survey on Water Harvesting

A field survey was conducted to identify the existing water harvesting structures, agricultural practices and associated activities in the watershed. The existing water harvesting structures were characterized and examined for their potential to store and convey runoff generated from the sub watershed area based on the crop water requirements for major crops grown. A well-structured questionnaire (Appendix 14) was developed to obtain important data which included household size, livestock size, size of farm land, types of crops grown, date of planting, and production constraints. Oral interviews with farmers, zonal and District Bureau of Agriculture and direct observations were used to obtain all the necessary information.

Accordingly both qualitative and quantitative data collection tools were used. The questionnaire was administered by trained enumerators to 31 farmers who have water harvesting structures in the watershed. In addition, the study also incorporated the findings of a survey conducted by Fitih *et al.* (2012), in which participatory rural appraisal techniques such as focus group discussion and key informant interviews were made on a sample of 100 households.

3.3. Soil Sampling and Laboratory Analysis

Soil samples were collected consisting of subsamples taken from nine locations within the sampling areas as described by Fery and Murphy, (2013). Subsamples were collected at three depths (0 – 20, 20 - 40 and 40 – 60 cm) from the sub watershed area, garden (Field 1) and main fields (Field 2) as illustrated in Figure 3 below. The soil (bulk) subsamples from each sampling area were then thoroughly mixed, packed and marked with proper identification codes in readiness for laboratory analysis of selected physical and chemical properties of the soil which included; particle size distribution, field capacity, permanent wilting point, available soil moisture, total nitrogen, phosphorus, organic matter and soil pH.

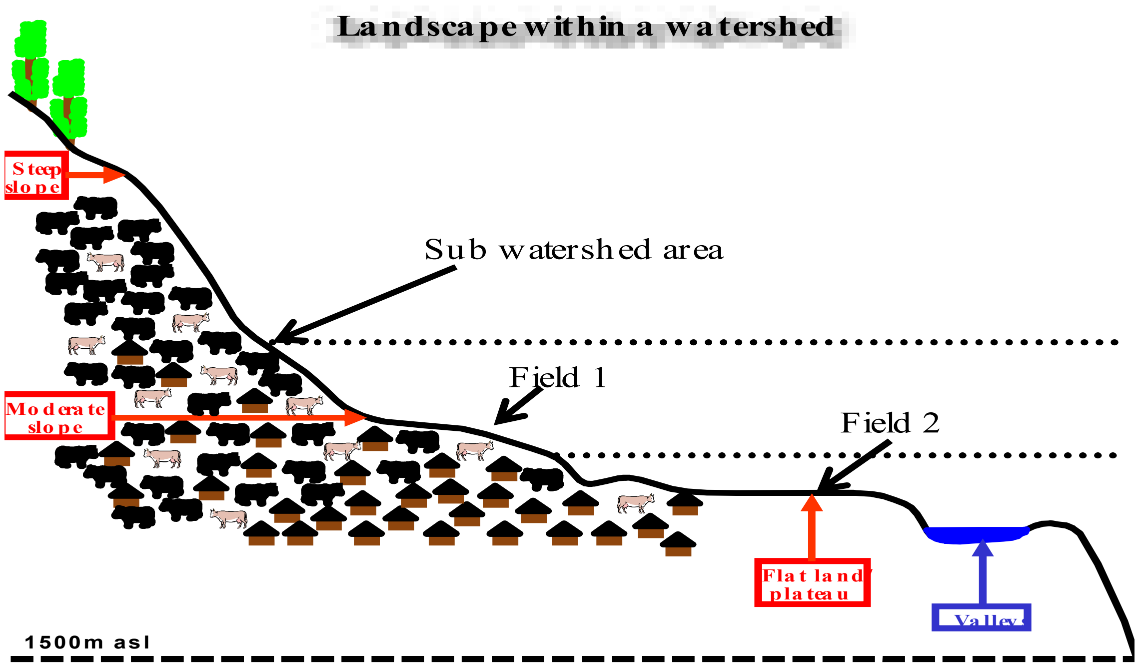

Figure 3: Landscape within Adulala watershed

Standard laboratory methods were used to determine important soil properties; particle size distribution was determined by hydrometer method (Bouyoucos, 1962), while Soil water retention at field capacity (FC = 0.33 bars) and permanent wilting point (PWP = 15 bars) were determined using pressure plate apparatus (Van Reeuwijk, 2006). Available water holding capacity (AWHC) was computed from FC and PWP, organic matter was determined by Walkly and Black method (Walkly and Black, 1934), total nitrogen and phosphorus were determined by Kjehdahl and Olsen methods (Olsen *et al.*, 1954) respectively, while values for infiltration rates were obtained from literature based on similar textural class of the soil in the study area (FAO, 2001).

3.4. Characterization of Existing Rainwater Harvesting Systems

Characterization of existing rainwater harvesting structures in the watershed was done to obtain characteristic data in the watershed, storage tanks and command areas. Data on the size, present land use and land cover of the sub watershed were collected through direct observations, interviews and measurement. Type of structures in the watershed, for the purpose of concentrating and diverting the runoff towards the storage tank, were also identified and measured. Data on the type, shape and capacity of the storage tanks was also obtained through observations and measurement. Size of potential irrigated area, type of major economical crops, methods of irrigation applied and other agronomical practices were obtained through discussions and direct observation. Soil samples were also collected from the catchment and command areas for the purpose of determining the hydrologic soil group of the catchment in order to estimate potential runoff amount as well as assessment of the suitability of the soils to support the growth of other crops which are not being grown in the Watershed.

3.5. Characterization of Climate Data

Thirty seven (37) years period long term climatic data (1977- 2013) for Adulala watershed was obtained from Melkassa Agricultural Research Centre and was checked for missing data, quality control and homogeneity before further analysis for rainfall-runoff and climate variability could be conducted. In practice, observing sites and instruments are moved, new instrumentation is used, sensor calibration and/or maintenance procedures change, observing methods and codes change, and environmental effects such as vegetation are not constant. Data collected over a long period therefore may not reflect uniform climatic conditions over the period for which normals are computed. Prior to computing period averages, the homogeneity of observed data with respect to non-climatic influences must therefore be assessed. If the data are found to be inhomogeneous, then it must be determined if the data can be adjusted so that the adjusted data set will reflect a uniform observing environment for a 30 year period (Guttman, 1998).

3.5.1. Estimating missing data

In patching the missing data before further analysis during the study a simple process of computing averages of the values observed on both sides of the gap was used as recommended by the World Meteorological Organization (WMO, 1989; WMO/TD No. 1186, 2003). One of the main applications of statistics to climatology is the estimation of values of elements when few or no observed data are available or when expected data are missing. Usually, execution of user projects cannot wait until there are enough meteorological or climatological observations; estimation is used to extend a data set. Estimating also has a role in quality control by allowing an observed value to be compared to its neighbors in both time and space (WMO, 2003).

3.5.2. Quality control

Quality control was performed on daily climate data using RClimdex (1.0) software (Zhang and Feng, 2002). The objective of quality control is to verify whether a reported data value is representative of what was intended to be measured and has not been contaminated by unrelated factors. It is important therefore to be clear from the outset what the readings of a particular data series are meant to represent. Data should be considered as satisfactory for permanent archiving only after they have been subjected to adequate quality control. The observer or automated observing system should apply quality control to ensure the time and station identification are correct, that the recorded values reliably reflect current conditions, and that there is consistency among the observed elements. These checks can be done either manually or by using automated procedures.

3.5.3. Homogenization

The RHtestsV4 software package was used to detect, and adjust for, multiple change points (shifts) that existed in minimum and maximum temperatures while RHtests_dlyPrcp package was used on precipitation data series based on the penalized maximal *F* test (Wang 2008a;Wang 2008b; and Wang *et al*. 2010). Analysis of climate data to detect changes and trends are more reliable when homogenized data sets are used.

A homogeneous climate data set is one in which all the fluctuations contained in its time series reflect the actual variability and change of the represented climate element. Most statistical methods assume the data under examination are as free from instrumentation, coding, processing, and other non meteorological or non climatological errors as possible.

3.5.4. Climate variability

The daily rainfall, minimum and maximum temperature data for a period of 37 years (1977-2013) were rearranged in a monthly and annual time step in Microsoft excel spread sheet. The rearranged data was averaged over the thirty seven year time span and analyzed in order to examine the annual, seasonal and monthly variabilities. In order to examine the temporal climate variability of Adulala for a thirty seven years (1977-2013) climatological period, trend analysis, standardized residual (anomaly), coefficient of determination (R^2), coefficient of variability (CV) and p-Value comparison were used in INSTAT (v 3.36) statistical software. CV was used to classify the degree of variability of rainfall events as less, moderate and high. When CV < 20% it is less variable, CV from 20% to 30% is moderately variable, and CV > 30% is highly variable. Areas with CV > 30% are said to be vulnerable to drought (Hare, 1983; Gebremichael *et al.*, 2014). The trend of a variable is computed using a linear regression model which is given by:

$$Y_1 = \beta_0 + \beta_1 X_1 + \varepsilon_i \quad (1)$$

where Y_1 is the i th scalar response, β_o is the intercept, X_1 is the i th vector of input data β_1 is the scalar coefficient (slope), ε_i is the i th scalar noise term which is independent random variable. The regression coefficients, β_o and β_1 can be estimated as $\hat{\beta}_0$ and $\hat{\beta}_1$ using least squares estimation, in which the sum of squared differences between the observed values of the response variable Y_i and the values predicted by the regression equation $Y_i = b_0 + b_1 X_i$ is minimized, leading to the estimates:

$$\hat{\beta}_1 = \frac{\sum_{i=1}^{n}(y_1 - \bar{y})(x_1 - barx)}{\sum_i = 1^n (x_1 = \bar{x})} \tag{2}$$

and

$$\hat{\beta}_0 = \bar{y} = \hat{\beta}_1 \bar{x} \tag{3}$$

where $\bar{y}$ and $\bar{x}$ are mean values (Everitt and Hothor, 2010).

Residuals are used to detect outlying values of the variable and checking the linear regression assumptions with respect to the error term in the regression model. Residuals can also be used to detect some forms of heteroscedasticity and autocorrelation. The standardized residual is defined as the ratio of raw residuals and their estimated standard deviation which is given by:

$$st_i = \frac{r_i}{\sqrt{MSE(1 - h_{ii})}} \tag{4}$$

where $r_i = y_i - \bar{y}_1$ is raw residuals, MSE is the mean squared error and h_{ii} is the leverage value for observation i that measures the effect of a particular observation on the regression predictions due to the position of that observation in the space of the inputs.

The coefficient of determination (R^2) indicates the variation of the climate variable with time in the linear regression model. A larger value of R^2 tells more variability of the dependent variable (climate variable) the linear regression model which is defined as:

$$R^2 = \frac{SSR}{SST} = 1 - \frac{SSE}{SST} \tag{5}$$

where: SSE is the sum of squared error, SSR is the sum of squared regression, SST is the sum of squared total. In general, R^2 measures how successful the fit is in explaining the variation of the data.

The P-value is a statistical measure that helps to determine whether or not the hypotheses are correct. P-value used to determine the result of the analysis within the normal range of values for the variables being observed. Usually, if the p-value of the dataset is below the pre-determined amount (say 0.05 which is the 95% significance level), the variability of the dataset had no meaningful effect on the result (Wilks, 2006).

3.5.5. Determination of start and end of the growing season

The rainfall amount and the number of rain days were used in INSTAT (v 3.36) statistical software (Stern *et al*., 2006) to determine the onset, cessation and length of growing season.

The start of the rainy season was defined as the first occurrence of at least 'X' mm rainfall totaled over't' consecutive days. This potential start can be a false start if an event, F, occurs afterwards, where F is defined as a dry spell of 'n' or more days in the next 'm' days (Stern *et al*., 1982). This approach was adopted and the earliest SOS was defined as the first occasion when the rainfall accumulated within a 3-day period was 20mm or more. Since the study area exhibits a bimodal rainfall pattern (short rain during February - May and long rains during June–September), April 1 was picked as the earliest possible planting date for the study area. Accordingly, 1st April was the potential starting date of the growing season that has at least 20mm within a 3 day period. The risk of failure in crops planted early was assessed by adding a caveat, i.e. the potential starting date of the growing season was not followed by a dry spell of 9 or more days in the first 30 days after planting.

In determining the end date, a dependable fixed 5.7 mm of evapotranspiration per day obtained at 80% probability of exceedance and 160 mm/m of the plant available soil water for local conditions were considered. On the other hand, the length of the growing season was taken as the difference between EOS and SOS respectively. The EOS is mainly dictated by stored soil water and its availability to the crop after the rainfall stops. The end of the rainfall season was defined as any day after 1st September when the soil water balance reaches zero.

3.5.6. Probability of dry spell length

The probability of dry spell lengths of 7, 10 and 15 days during the growing season were determined from the Markov chain model to obtain an overview of dry spell risks during the crop growing season. Daily rainfall data was fitted to a simple Markov chain model. The chance of rain was assessed both when the previous day was dry, i.e. the chance that a dry spell would continue, and also when the previous day was rainy, i.e. the chance that a rainy spell would continue, which is known as a Markov chain (Stern *et al*., 2006; Stern and Cooper, 2011).

3.6. Rainfall- Runoff Analysis for Rainwater Harvesting

3.6.1. Estimation of design rainfall of the area

The design rainfall for the watershed was calculated from the long term rainfall data through a probability analysis as described by FAO (1991).

The probability analysis involved obtaining long term annual rainfall totals (1977-2013) for the cropping seasons in the study area. The annual rainfall totals were then re-arranged in a descending order with $m = 1$ for the largest and $m = 37$ for the lowest value. The probability of occurrence P (%) for each of the ranked observations was calculated from Eq.6 (FAO, 1992).

$$P(\%) = 100 \frac{m}{(N + 1)} \tag{6}$$

Where; P = probability (%) of the observation of the rank m, m = the rank of the observation and N = total number of observations used.

The ranked observations and corresponding probabilities were plotted in Microsoft Excel and an annual runoff producing design rainfall (P) value was obtained at 80% probability of exceedance which represents the dependable annual rainfall representing maximum allowable deficit.

The return period T (in years) was derived from the equation (FAO, 1992).

$$T = \frac{100}{P}(year) \tag{7}$$

where; P = probability in % of the observation

3.6.2. Estimation of design runoff harvested

The amount of runoff water harvested from the catchment area is a function of the amount of runoff created by the rainfall on the catchment area. Potential runoff depth being harvested in the watershed was estimated through a rainfall- runoff analysis using the SCS curve number method (SCS, 1986);

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \tag{8}$$

Where Q is runoff depth (mm), P is average monthly design rainfall depth (mm), and S potential maximum retention (mm).

The retention capacity (S) of the watershed was predicted using the curve number as defined by Soil and Conservation Services of United States of America (SCS, 1986).

$$S = \frac{25400}{CN} - 254 \tag{9}$$

In which, CN is the runoff curve number or hydrologic soil-cover complex number; is a kind of runoff coefficient that has a relationship to soil type, and its use, antecedent soil moisture, and hydrologic condition of the watershed.

For determining the CN value in the sub watershed, soil and corresponding land use data were used. The criteria used for classifying each soil type into hydrologic soil group as indicated in SCS (1964) is shown in Appendix Table 2.

Considering the existing land use and hydrologic soil group for the sub watershed within the watershed, the CN value of the soil was estimated using rated table values (USDA-SCS 1964).

In the above SCS rainfall-runoff model, the volume of precipitation (P) used were determined from the 80% dependable average monthly rainfall amount corresponding to the maximum water deficit. Using individual S (potential maximum water retention characteristic) and a single P value, runoff Q (mm) was determined for the sub watershed area.

3.7. Crop Water Requirements

Crop water requirements for major crops grown in the area were estimated from long term (1977-2013) monthly reference crop evapotraspiration (ET_o) obtained at 80% probability of exceedance in EasyFit 5.6 software and crop coefficients at different growth stages in CROPWAT 8.0 software.

3.7.1. Reference evapotranspiration (ET_o)

In estimating ET_o, climatological records of (sunshine duration .hr/day), maximum and minimum air temperature (°C), humidity (%) and wind speed (Km/day) at 2 meters height were used in FAO Penman Monteith method in CROPWAT 8.0 software for windows.

3.7.2. Crop parameters

In addition to meteorological data used to calculate reference crop evapotranspiration (ET_o), crop related data was also required to estimate the crop water requirements on daily, decadal, monthly and seasonal bases. Crop water requirements were computed for major economical crops in the study area which included: *Teff*, maize, wheat, beans, citrus, small (cabbage, chill, spinach, rape etc) and large (tomato, egg plant) vegetables classified by FAO (2001).

Lengths of total growing periods of the crops were obtained from farmers. The planting date obtained from the farmers was 1^{st} June during the onset of JJAS rain in the study area as confirmed by the farmers. Crop coefficients (Kc) defined as the ratio of the actual evapotranspiration of a disease free crop grown in a large field adequately supplied with water to the reference evapotranspiration rooting depth, depletion level and other agronomic parameters were obtained from FAO guidelines for each growth stage (Doorenbose and Kassam, 1979; Allen *et al*., 1998). While those for *teff* were 0.6 for initial, 0.8 development, 1.1 maturity and 0.8 for late growth stages (Yenesew, 2015).

3.8. Catchment to Command Area Ratio

The following equation was used to estimate the catchment/ command area ratio in the study area ((FAO, 1994).

$$\frac{\text{Catchment area}}{\text{Command area}} = \frac{\text{CWR} - \text{effective rainfall}}{\text{Design rainfall x runoff coefficient}} \quad (10)$$

The effective rainfall and crop water requirement for each crop were used. The design rainfall was estimated at 80% probability of exceedance as described above, while the effective rainfall was also estimated using dependable rainfall method in CROPWAT 8.0 software. Runoff coefficient of the catchment area was derived from Schwab *et al*. (1981).

3.9. Size of the Catchment Area

The size of catchment area contributing to the existing storage capacity in the study area was determined by using the following equation (Gould and Petersen, 1999; MOA, 2002).

$$A = \frac{1000V}{PC} \quad (11)$$

where,

A = catchment area in m^2.

V = water storage capacity in m^3.

P = annual rainfall in mm.

C = runoff coefficient for a given catchment.

The water storage capacity (V), was determined from measurement of the current storage capacity in the watershed while the runoff coefficient (C), was obtained from Schwab *et al*. (1981) and the value was 0.3 for hilly 10-30% slope sandy loam texture.

4. RESULTS AND DISCUSSION

4.1. Awareness and Usage of Water Harvesting Technologies

The practice of water harvesting is mainly centered on ex-situ and in-situ water harvesting in the study area. The survey results indicated that farmers are knowledgeable about both ex-situ and in-situ practices. However, usage of these technologies in still low (Table1). The mass testing and popularization of tie ridges implemented by MARC on nearby on-farm sites (i.e. at Adulala Watershed) created good awareness about this technology. In general, farmers in the watershed showed more awareness and higher rate of use of the more common technologies like Terraces/Trenching, animal manure and compost. The recent government initiative on natural resource management on watershed bases created good awareness and use about Terraces/Trenching. In line with this initiative, mass mobilization of farmers to rehabilitate degraded communal lands and conserve soil and water on farm lands at watershed level was done by district office of agriculture.

Table 1. Awareness and level of usage of water harvesting technologies

Technology	Awareness		Usage	
	Yes/No	%	Yes/No	%
Tide ridges	No	38.0	No	63.8
	Yes	62.0	Yes	36.2
Terraces/Trenching	No	6.0	No	16.5
	Yes	94.0	Yes	83.5
Rainwater harvesting	No	6.2	No	69.9
	Yes	93.8	Yes	30.1
Irrigation	No	9.1	No	91.6
	Yes	90.9	Yes	8.4
Conservation farming	No	20.7	No	37.5
	Yes	79.3	Yes	62.5
Mulching	No	27.5	No	59.5
	Yes	72.5	Yes	40.5
Animal manure	No	2.1	No	8.3
	Yes	97.9	Yes	91.7
Compost	No	3.0	No	19.8
	Yes	97.0	Yes	80.2
Cover crops	No	21.1	No	45.8
	Yes	78.9	Yes	54.2

4.2. Characterization of Water Harvesting Structures in the Watershed

Out of 923 households, 31 have water harvesting structures with a mean household size of eight (8) people. The low usage of water harvesting structures is attributed to lack of financial capacity for the small holder farmers as construction of these structures is expensive and too laborious. Thirty eight water harvesting structures have been constructed from the period of 1995 - 2011 with assistance from MARC and Non-Governmental Organizations (NGOs) which include: World Vision Ethiopia and Sasakawa Global 2000.

The watershed has an area of 2,747.7 hectares of which the 38 tanks are filled with runoff generated from an area of about 2.2 Hectares. Out of 38 underground tanks, 34 are of hemispherical shape with a volume of 90 m^3 each while 4 have a rectangular shape with a volume of 320 m^3 each hence bringing the total volume to 4340 m^3 (Appendix Table 3). Both the hemispherical and rectangular tanks are lined with cement. Runoff from the sub watershed is conveyed to the tanks through open earthen channels. However, a lot of runoff is lost through seepage hence lining them with concrete would reduce such losses. A rectangular type silt trap is constructed at 3 m from the storage tank. The size of silt trap is 100 centimeters deep, 250 centimeters long and 150 centimeters wide. The compartment is made at a distance of 150 centimeters from the inlet and the spillway is made on the compartment at 30 centimeters depth and 40 centimeters width. The size of the channel connecting the catchment to the silt trap is kept as 20 centimeters deep and 40 centimeters wide. The outlet from the silt trap to the storage tank is 15 centimeters in diameter. However, a lot of silt accumulated in the silt traps which indicate that farmers do not desilt the traps due to negligence. A lot of effort is thus required to persuade farmers to ensure that silt traps are cleaned as no funds are required.

The sub watershed area is characterized by grass and a mixture of wood lots and shrubs that are sparsely populated. This classification was done earlier based on the methodologies of Ex- LUPRD/FAO and WBISPP (Westphall, 1975; ORS, 2002). The sub watershed was earlier under open grazing. However, with the intervention through the promotion of soil and water conservation programme by the district agricultural office over the years, the area is now protected from grazing. This has resulted in establishment of moderate vegetation. The sub watershed area has a slope ranging from 15-25 %.

Below the sub watershed area is the dwelling place on which water harvesting tanks are built. This area has a slope ranging from 3-8 %. Around the dwelling place, individual households have an average piece of land of about 0.25 ha which amounts to 7.75 ha for the 31 households who have water harvesting tanks on which they grow vegetables. The crops are planted in the rain season and supplementary irrigation is practiced during dry spells. Buckets are commonly used as irrigation methods while only two farmers use treadle pumps due to high maintenance cost involved. In addition, the harvested water is also used for livestock and domestic purpose as the watershed has limited water sources. At the foot of the dwelling area are the low laying fields with slope less than 3 %. Main season crops are grown here.

Major crops grown in the watershed during the main season include; maize, *teff*, beans and wheat, while minor crops include; onion, tomato, cabbage, pepper, cassava and chilli. Also planted around the homestead are orchard crops which include; orange, mango and lemon (Table 2).

Table 2: Major crops grown in Adulala watershed

S.No	Main season (rainfed)	Variety	DM*	Area (m^2)
1	Teff	Kuncho	90	4375
2	Maize	Melkassa II	125	4375
3	Beans	Awash I	90	4375
4	Wheat	Kubsa	90	4375

*DM = days to maturity

S.No	Main season (rainfed/supplemental irrigation)	Variety	DM*	Area (m^2)
5	Citrus (Orange, lemon)	-	365	1 250
6	Small vegetables (Onion, cabbage, pepper, chilli)	-	95	850
7	Large vegetables (Tomato, egg plant)	-	120	400

*DM = days to maturity

4.3. Soil Physical and Chemical Properties

As shown in Table 3 results from soil analysis show that the soil pH for Adulala watershed ranged from 7.29 to 8 in the sub watershed, 7.08 to 7.82 in the garden fields (field 1) around the homestead and 7.35 to 8.03 in the main fields (field 2). In general, the soil pH in the watershed represents a slight alkaline condition. This is in conformity with the soil reaction (pH) rating established by Tekalign (1991).

In crop production, the optimum pH for the growth of most crops is about 6 to 7. Soil pH affects both nutrient availability and microbial activity. At pH levels less than 5.5, availability of N, P, K, calcium (Ca), magnesium (Mg), sulfur (S), and molybdenum (Mo) is reduced. In addition, pH levels less than 5.5 reduce the activity of important microbial decomposers, which will greatly depress the biological conversion of organic material to useable nutrients for plant growth. It is thus important to monitor pH and apply agricultural limestone according to soil test recommendations if the pH falls below 6.0. Further, Rosen and Bierman (2015), reported that soils with a pH between 7 and 8.3 are in a range that will promote microbial activity, but may limit P, iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn) availability. Use of organic matter amendments and organic foliar products will help increase availability of these nutrients under alkaline conditions.

Phosphorus ranged from 1.48 to 151.23 ppm. According to Landon (1991) rating, the average available P contents vary from low to high P status. Further, Tekalign *et al*. (1991) reported that 8.5 mg P kg^{-1} of soil was the critical level for some crops such as faba bean on major and/or agriculturally important soils of Ethiopia. Considering these levels of soil P, the amount of available P observed in the soils of the current study are considerably high. In general, existence of low contents of available P is a common characteristic of most of the soils in Ethiopia (Negassa and Gebrekidan, 2003) which is contrary to the P content observed in the soils of the current study area. However, Blackburn *et al*. (2012), reported that the target soil analysis ranges for vegetables have Phosphorous (P) at 50 -70 ppm while Nitogen (N) as an important element for plant growth, its levels are not considered as the element is highly mobile and levels in the soil vary dramatically due to irrigation and rainfall intensity. Nitrogen availability in the soil is a function of organic matter levels. The P content of the soil is probably the most important factor to monitor as it can take three to four years to reach the desired level due to fixation in the soil.

Total nitrogen ranged from 0.042 to 0.126 %. These values fell within the range suggested by Landon (1991) as low. This implies that the soils of the study area are deficient in N to support optimal growth and development of crops.

Organic matter ranged from 1.63 to 5.44 percent. According to the rating of soil OM content established by Tekalign (1991), the soils had low to medium OM contents. The reasons for the low and moderate OM levels in these soils could be due to intensive cultivation of the land, which encourages oxidation reaction, and the total removal of crop residues for animal feed and source of energy. According to Zewdie (1999), variability of soil OM has also been related to land use history and the associated management practices in other soils of Ethiopia. Therefore, these nutrient levels are a guide to aim for when making decisions on fertilizer requirements and when introducing new crop to the area.

The table also shows that the sub watershed area and garden fields (field 1) are dominated by sandy loam soils as evidenced by 50 to 57.5 percent sand and 32.5 to 40 percent silt content respectively, while the main fields (field 2) are dominated by loam soils.

The available water holding capacity (AWHC) in fields 1 and 2 ranged from 127.71 – 151.61 and 153 – 171.75 mm/m respectively. These values are in conformity with values reported by FAO (2002) for both Sandy Loam and Loam soils respectively.

Table 3: Selected soil physical and chemical properties for Adulala watershed

Field No	Site	Depth cm	pH	TN %	P ppm	OM %	Sand %	Silt %	Clay %	Textural Class	AWHC mm/m
1	1	0-20	7.08	0.084	42.24	2.60	57.5	32.5	10	SL	127.71
1	1	20-40	7.22	0.056	30.41	3.15	57.5	35	7.5	SL	151.61
1	1	40-60	7.3	0.042	36.23	2.19	57.5	35	7.5	SL	153.52
1	2	0-20	7.29	0.07	39.33	3.72	57.5	35	7.5	SL	127.71
1	2	20-40	7.3	0.07	38.75	4.62	57.5	35	7.5	SL	151.61
1	2	40-60	7.23	0.056	39.33	3.98	57.5	35	7.5	SL	153.52
1	3	0-20	7.24	0.07	27.50	5.19	52.5	40	7.5	SL	127.71
1	3	20-40	7.74	0.07	1.48	3.38	52.5	40	7.5	SL	151.61
1	3	40-60	7.82	0.042	40.06	2.40	45	47.5	7.5	Loam	153.52
2	1	0-20	8.03	0.042	17.96	4.02	45	47.5	7.5	Loam	154.73
2	1	20-40	7.55	0.056	19.71	3.09	45	45	10	Loam	171.75
2	1	40-60	7.39	0.07	20.29	2.40	45	45	10	Loam	165.24
2	2	0-20	7.42	0.07	17.77	3.31	45	45	10	Loam	154.73
2	2	20-40	7.35	0.07	25.72	3.05	45	45	10	Loam	171.75
2	2	40-60	7.36	0.084	23.78	3.74	45	45	10	Loam	165.24
2	3	0-20	7.43	0.056	21.33	5.44	40	32.5	27.5	Loam	154.73
2	3	20-40	7.74	0.042	18.42	2.72	37.5	47.5	15	Loam	171.75
2	3	40-60	7.76	0.126	22.49	1.63	37.5	35	27.5	Loam	165.24

SL = Sandy Loam, SCL = Sandy Clay Loam, SL = Sandy Loam

Table 3: (Continued)

Description	Site	Depth (cm)	pH	TN (%)	P (ppm)	OM (%)	Particle size (%)			Textural Class	AWHC (mm/m)
							Sand	Silt	Clay		
Sub watershed	1	0-20	7.39	0.126	17.84	1.63	50	25	25	SCL	-
Sub watershed	1	20-40	7.36	0.112	21.13	3.67	52.5	22.5	25	SCL	-
Sub watershed	1	40-60	7.29	0.07	16.48	2.85	50	22.5	27.5	SCL	-
Sub watershed	2	0-20	7.5	0.056	25.98	2.85	52.5	32.5	15	SL	-
Sub watershed	2	20-40	7.82	0.056	19.58	2.04	55	32.5	12.5	SL	-
Sub watershed	2	40-60	8	0.126	19.19	1.90	52.5	37.5	10	SL	-
Sub watershed	3	0-20	7.9	0.126	151.23	4.62	50	40	10	SL	-
Sub watershed	3	20-40	7.92	0.126	17.26	3.65	52.5	35	12.5	SL	-
Sub watershed	3	40-60	7.9	0.126	16.09	3.67	57.5	32.5	10	SL	-

4.4. Quality Control

Rainfall data showed consistency in quality as no inconsistencies in data were detected. Inconsistency was detected in minimum and maximum temperature. However, this was taken as human error in recording and was thus corrected. As evident in Table 4**Table 3**, the maximum value is lower than the minimum value hence the two values might have been recorded inter changeably.

Table 3: Quality control results for minimum and maximum temperature

Year	Month	Day	Precipitation	Tmax	Tmin	Tmax-Tmin
2010	8	9	13	17	17.5	-0.5

4.5. Homogeneity Test

Daily rainfall data series showed inhomogeneity with one change point on 25/02/1978. This was evident by the test statistic (PFmax = 16.1306) being greater than the upper limit of the confidence interval of PFmax (10.6673 - 13.3080) at $p< 0.05$. This change could have been as a result of any of the causes of inhomogeneity. However, the data series were thus adjusted for homogeneity to only reflect changes in weather conditions (Figure 4). On the other hand, no change points were detected in both minimum and maximum temperatures hence, the data series were homogeneous (Figure 5 and 6). These results could not be compared to previous works as no results have been published on quality control and homogeneity test for the station inquestion.

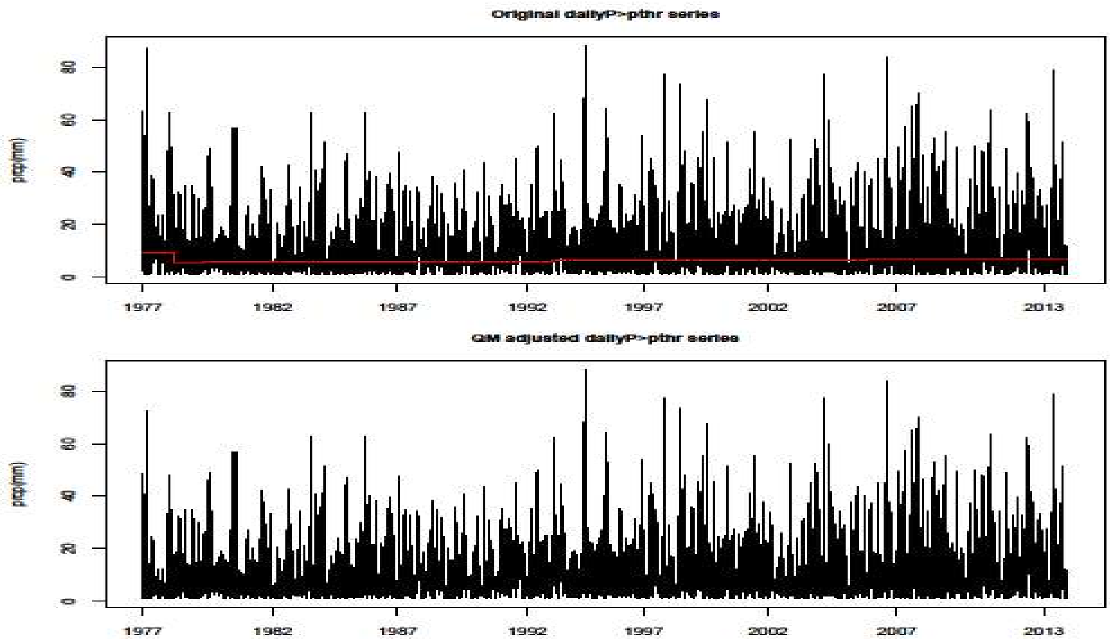

Figure 4: Original daily rainfall series with one change point and an adjusted (homogeneous) series

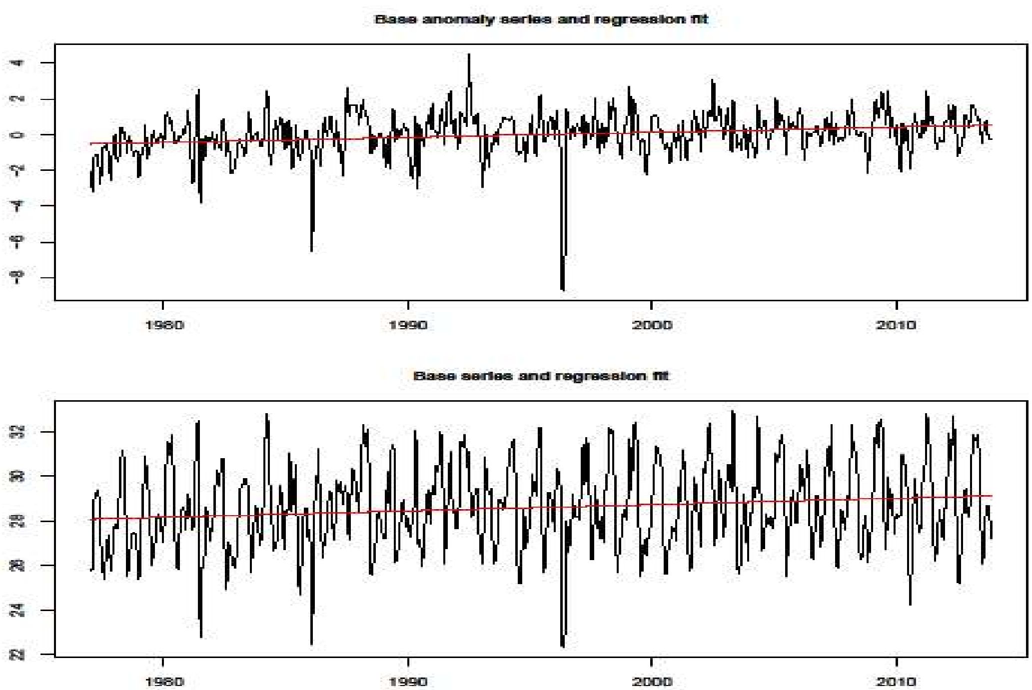

Figure 5: Maximum temperature series with regression fit (Homogeneous series)

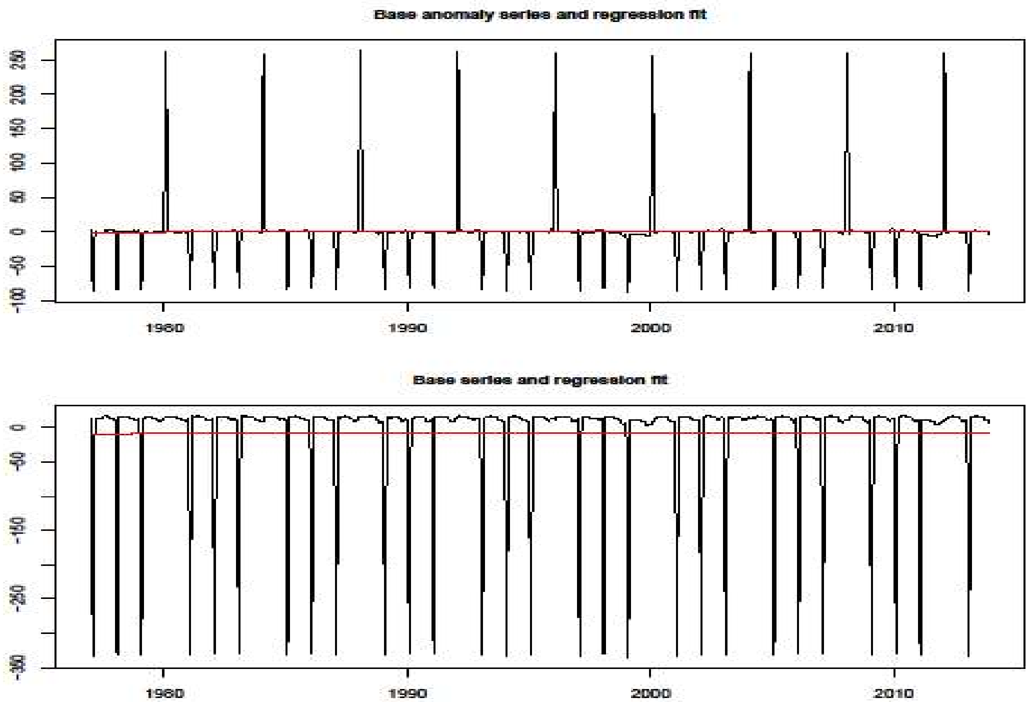

Figure 6: Minimum temperature series with regression fit (Homogeneous series)

4.6. Climate Variability

4.6.1 Rainfall

As shown in Figure 2 above, Adulala watershed has a bimodal rainfall pattern. Similarly, various authors have reported the bimodality of rainfall pattern in CRV of Ethiopia (Kassie *et a.,* 2012; Girma, 2005). The watershed has a mean annual rainfall of about 820 mm based on the long term rainfall data. The lower (25 percentile), median (50 percentile) and upper quartile (75 percentile) caps of the whiskers in Figure 7 give a useful explanation of the existing variability in rainfall. The variability in *Belg (*short season FMAM) rainfall with 44.8% C.V is high as compared to *Kiremt* (main season JJAS) and annual rainfall with 18 and 18.6 % C.V respectively (Table 5 and Figure 7). For instance, 50% of the 37 years annual rainfall ranged from 910.55 to 711.8 mm, while of the 50% the short and main seasons ranged from 112.1 to 344.5 mm and 500.25 to 605.8 mm respectively. Thus for crop production purpose, the short season cannot support the growth of crops that have high water requirements. The inter annual rainfall variability showed a significant ($p < 0.05$) increasing trend of 1.86 mm per year while the

JJAS season equally showed a significant ($p < 0.05$) but highly increasing trend at a rate of 3.678 mm per year (Figure 8). The FMAM season showed a non significant decreasing trend of -1.246 mm per year. On the other hand, the monthly pattern for the 37 years period showed a low increasing trend of 0.044 mm per year (Table 4 and Figure 9). The year to year rainfall variability expressed in terms of normalized rainfall anomaly Figure 10, shows anomalies in seasonal rainfall below normal and above normal. For instance, results show that the study area experienced drought in 1984/1985, 1994/1995, and 2000/2001 seasons. These findings are in conformity with findings reported by Kidane in 2010 about years of drought and floods in Ethiopia.

Table 4: Descriptive statistics and variability of rainfall for Adulala watershed (1977-2013)

Rainfall summaries	FMAM (mm)	JJAS (mm)	Annual total rainfall (mm)
Minimum	45.3	389	548.7
Quartile 1 (25%ile)	112.1	500.25	711.8
Quartile 2 (50%ile)	189.1	560.7	810.1
Quartile 3 (75%ile)	258.6	605.8	910.55
Maximum	344.5	789.6	1312.4
Mean	191.07	558.97	829.21
Trend	-1.246	3.678	1.86
R-squared	0.157	0.024	0.019
CV (%)	44.8	18	18.6
P- Value	0.35	0.0151	0.019

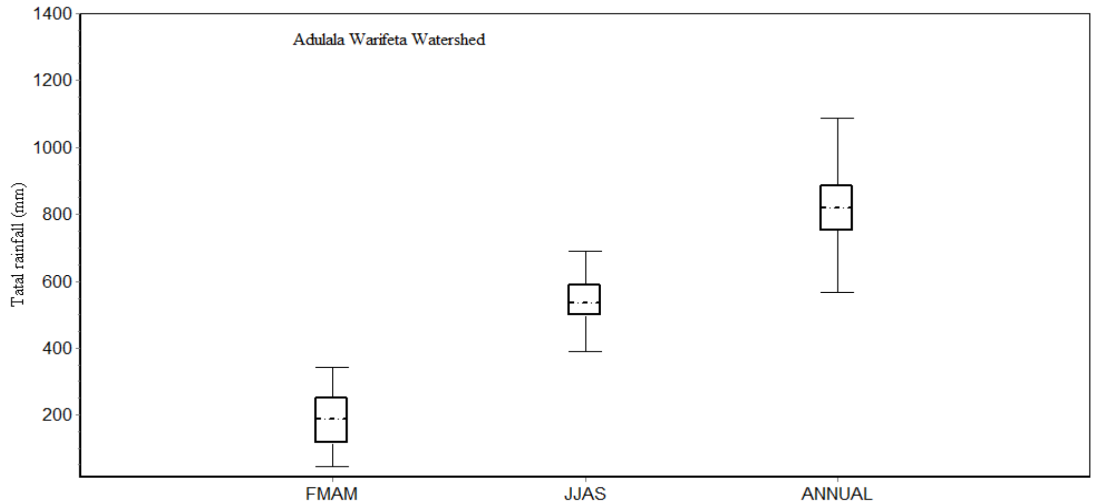

Figure 7: Seasonal (FMAM and JJAS) and annual rainfall variability for Adulala watershed (1977 – 2013)

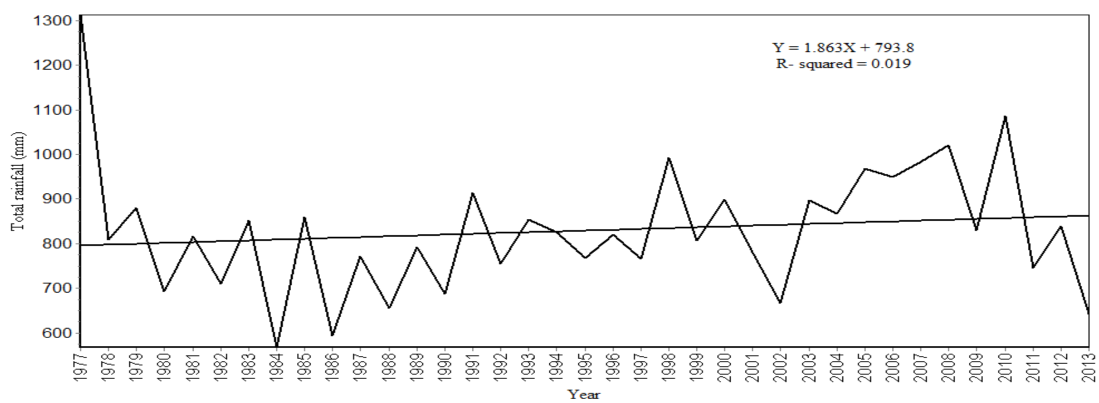

Figure 8: Inter-annual rainfall variability

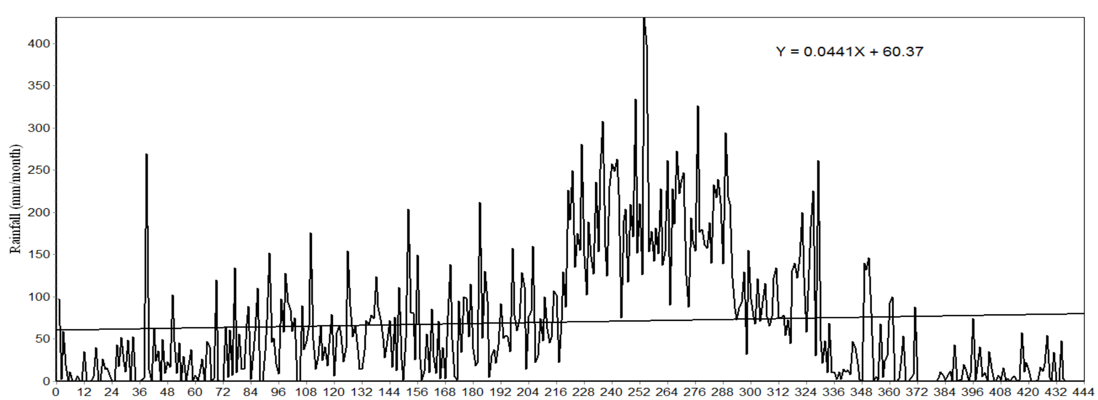

Figure 9: Monthly rainfall pattern

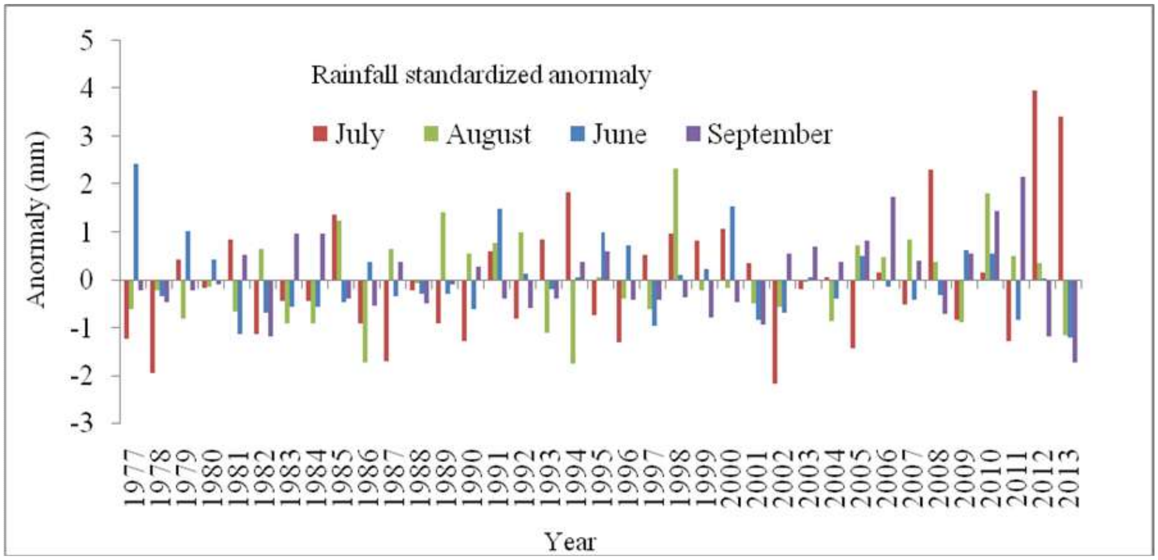

Figure 10: Rainfall trend and standardized anomaly for JJAS season.

4.6.2. Temperature

Maximum temperature

Table 6 and Figure 11 show the temporal mean, trend, coefficient of determination and p-values of maximum temperature for annual, *Belg* (FMAM) and *kiremt* (JJAS) time steps. The watershed has a mean annual maximum temperature of 28.75°C based on the long term temperature data. The lower (25 percentile), median (50 percentile) and upper quartile (75 percentile) caps of the whiskers in Figure 11 gives a useful explanation of the existing variability in maximum temperature. The variability in *Belg (*short season FMAM) mean maximum temperature with 3.1% C.V is high as compared to *Kiremt* (main season JJAS) and mean annual maximum temperature with 2.9 and 2.1% C.V respectively. However, the temporal variability of maximum temperature showed less variability at a lower rate though the changes are highly significant ($p < 0.05$) during the 30 years time period.

The regression model showed that the maximum temperature had an increasing trend at all time scales. The variability of maximum temperature at both annual and FMAM time scales is statistically significant ($p < 0.05$) while that of JJAS time scale is non significant.

Table 6: Descriptive statistics and variability of mean maximum temperature for Adulala watershed (1977-2013)

Mean maximum temperature Summaries	FMAM (^{0}C)	JJAS (0C)	Mean annual Tmax (^{0}C)
Minimum	28.17	26.07	27.14
Quartile 1 (25%ile)	29.89	27.15	28.37
Quartile 2 (50%ile)	30.63	27.43	28.75
Quartile 3 (75%ile)	31.35	27.98	29.14
Maximum	31.8	29.67	30.48
Mean	30.51	27.62	28.75
Trend	0.0529	0.0147	0.0278
R-squared	0.3716	0.0387	0.242
CV (%)	3.1	2.9	2.1
P- Value	0.0001	0.2432	0.002

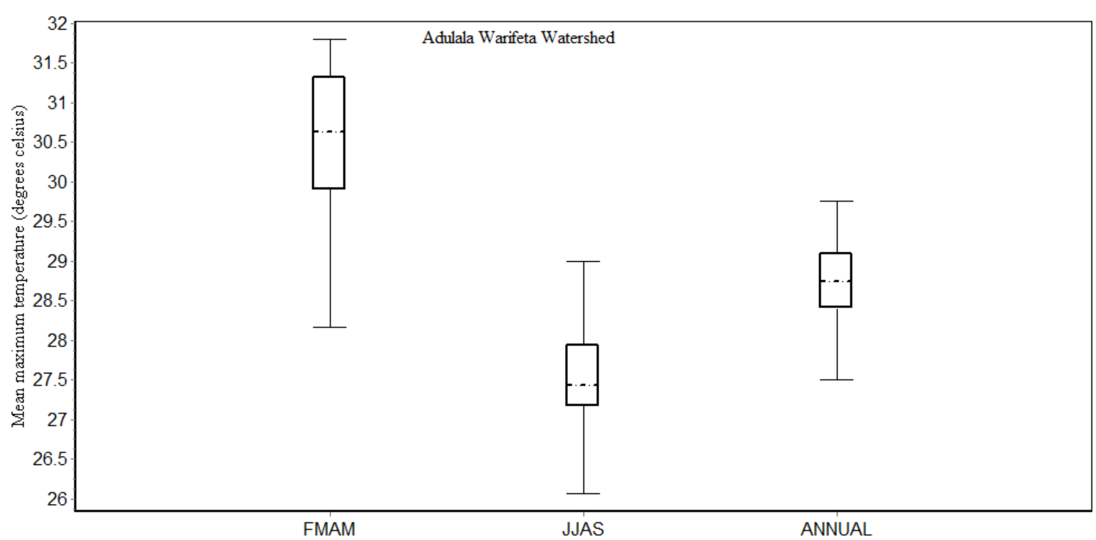

Figure 11: Seasonal (FMAM and JJAS) and mean annual maximum temperature variability for Adulala watershed (1977 – 2013)

Minimum temperature

Table 7 and Figure 12 show the temporal mean, trend, coefficient of determination and p-values of minimum temperature for annual, *Belg* (FMAM) and *kiremt* (JJAS) time steps. The watershed has a mean annual minimum temperature of 13.87°C based on the long term temperature data (Table 7). The lower (25 percentile), median (50 percentile) and upper quartile (75 percentile) caps of the whiskers in Figure 12 gives a useful explanation of the existing variability in minimum temperature. The variability in *Belg (*short season FMAM) minimum temperature with 8 % C.V is lower as compared to *Kiremt* (main season JJAS) and mean annual minimum temperature with 8% C.V each. However, the temporal variability of minimum temperatures showed slightly higher variability than the maximum temperature. The regression model showed that the minimum temperature had a decreasing trend at all time scales. The variability of minimum temperature at both annual and FMAM time scales is statistically non significant.

Table 7: Descriptive statistics and variability of mean minimum temperature for Adulala watershed (1977-2013)

Mean minimum temperature summaries	FMAM (^{0}C)	JJAS (^{0}C)	Mean annual Tmin (^{0}C)
Minimum	10.8	10.28	9.48
Quartile 1 (25%ile)	14.675	15.39	13.78
Quartile 2 (50%ile)	15.03	15.78	14.08
Quartile 3 (75%ile)	15.72	16.1	14.46
Maximum	16.91	16.44	15.31
Mean	14.952	15.404	13.875
Trend	-0.0331	-0.0019	-0.0198
R-squared	0.0888	0.0002	0.034
CV (%)	8	8.4	8.4
P- Value	0.0733	0.9265	0.2745

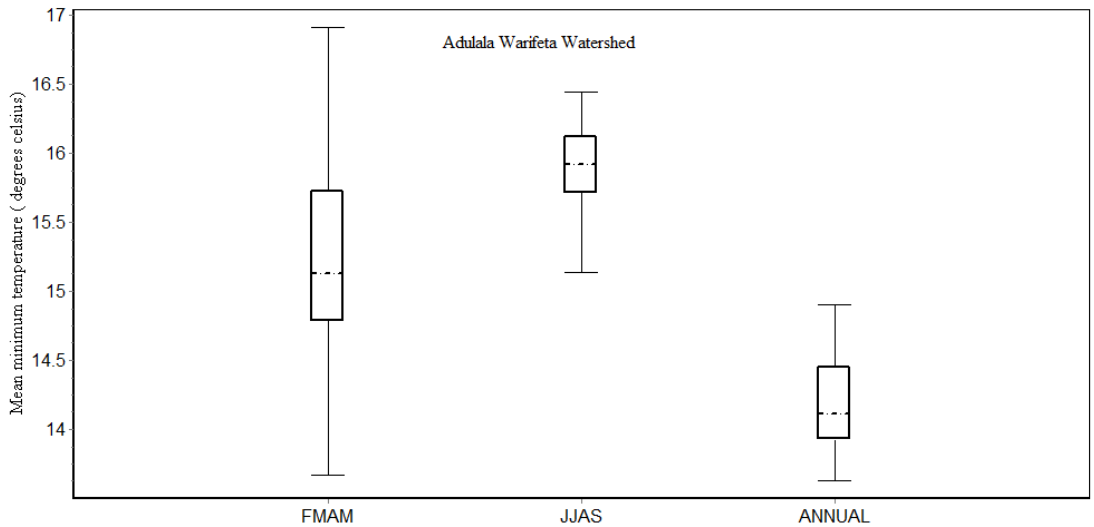

Figure 12: Seasonal (FMAM and JJAS) and mean annual minimum temperature variability for Adulala watershed (1977 – 2013)

4.6.3. Impact of temperature and rainfall amounts on crop production

Fischer *et al*. (2002) reported that changes in rainfall amounts and patterns, in addition to shifts in thermal regimes, influence local seasonal and annual water balances. These in turn affect the distribution of periods during which temperature and moist conditions permit agricultural crop production. According to IPCC (2007), increase in temperature will adversely affect crops, especially in semi-arid regions where already heat is a limiting factor of production. Increased temperatures also increase evapotranspiration rate of soil and water bodies as well as evapotranspiration rate of plants and increase chance of severe drought. Therefore, this means that with warmer temperatures plants require more water. Hence adaptation to climate variability through promotion of rainwater harvesting for crop production is crucial.

4.6.4. Start and end of the growing season

The distribution of useful rainfall features listed above formed a good starting point for examination of the series. The lower (25 percentile), median (50 percentile) and upper quartile (75 percentile) caps of the whiskers in Figure 13, provide a useful explanation of the existing variability in the rainfall features while Figures 14 and 15 present the inter-annual variability and trend of the start and end of the season. In Figure 13 and Table 8, for instance the respective lower and upper quartiles for the start of the season fall between 92 and 178 DOY (about three months) with 20.1% C.V. Similarly, Mesay (2006), reported that the onset of *Belg* is highly variable, with standard deviation across the country ranging from 12 to 65%. Further, this upper quartile (75 percentile) statistic extends up to the 178 DOY (last days of June). The earliest potential onset date of the growing season is day 92 (1^{st} April) and the latest is day 202 (20^{th} July). The variability in the start of the season is non significant while increasing at a decreasing trend of 0.0421 days per year. The main rainy season terminates during the second week of September (255 DOY) once in four years time and terminates earlier than 285 DOY (2^{nd} week of October) in three out of four years while the earliest possible end date of the growing season is day 245 (1^{st} September). The variability in the end of the season is highly significant ($p < 0.05$) with an increasing trend of 0.8063 days per year with a lower C.V of 6.2%.

Accordingly, the main growing season would not extend beyond the second week of October. The lowest (6.2% C.V) and the much smaller box for the rainfall end date in Figure 13 indicate that the end dates vary over a short time span at Adulala. Therefore, as less variability implies that patterns could be more understood, decisions pertaining to harvesting and storage could be made more easily than the decisions pertaining to planting (Girma, 2005).

Similarly, the number of monthly rain days for FMAM season ranged from 0-15 days with coefficient of variation of 42.6 – 121.4 %. Such variability is highly variable (Table 9). On the other hand, the monthly total rainfall for FMAM ranged from 1.1 – 203 mm with coefficient of variation of 63.4 – 98.2 % (Table 10). However, such lower amounts of monthly total rainfall would not adequately support crop growth. The JJAS season monthly rain days ranged from 1 – 21 days with coefficient of variation of 15.8 – 44.8 %. Its monthly total rainfall ranged from 1.8 – 429.4 mm. However, not all of this rainfall amount is utilized by crops as effective rainfall due to various losses such as evaporation, interception, seepage and runoff. A further note could also be made from Table 8 and Figure 15, that the length of the growing season is dependent mainly on the onset date. The LGS is lower than 96.5 days in only 25 % of the years, while it is lower than 142 days in 75% of the years. However, over the 37 years period the length of the growing season had shown an increasing trend of 1.228 days per year (Figure 16). The LGS is highly correlated with the starting date of the growing season (R- squared= 0.64). For instance, 64% of the variability in length of the growing season at Adulala is explained by the starting time of the growing season (Figure 17). Weak correlations exist between LGS and EOS as well as between EOS and SOS with R- squared less than 0.05 (Figures 18 and 19).

However, according to Girma (2005), the early onset date suggests that crop cultivars of the longer maturity type could do better than with the late onset date. The issue of rainfall duration deserves further attention, in that one needs to know the type and level of risks of yield loss associated with cultivars of different maturity categories, requiring different amounts of water during a sequence of growth stages. It is only then that one can confidently pinpoint the most suitable maturity cultivars to be planted in seasons with different onset date scenarios.

Table 8: Descriptive statistics and variability of important rainfall features during summer season for Adulala watershed (1977-2013)

Rainfall features summaries	SOS	EOS	LGS
Minimum	92	245	68
Quartile 1 (25%ile)	129	255	96.5
Quartile 2 (50%ile)	164	273	121
Quartile 3 (75%ile)	178	285	142
Maximum	202	305	205
Mean	154.54	271.43	122.81
Trend	-0.4215	0.8063	1.228
R-squared	0.0215	0.1854	0.1594
CV (%)	20.1	6.2	27.1
P- Value	0.3867	0.0078	0.0144

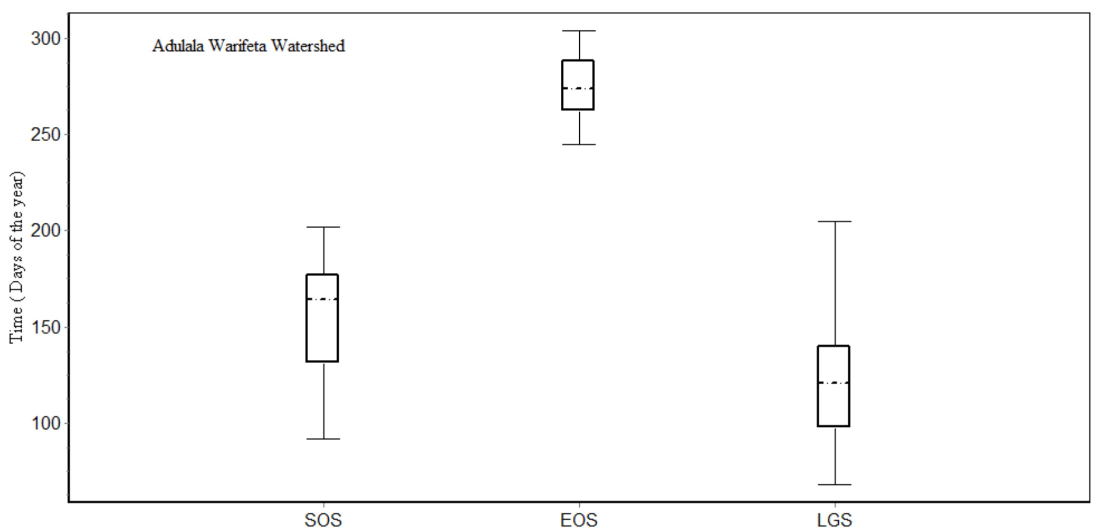

Figure 13: Variability of important rainfall features at Adulala watershed

Table 9: Descriptive statistics of monthly rain days for FMAM and JJAS seasons

Months	Min	Quartile 1 (25%ile)	Quartile 2 (Median)	Quartile 3 (75%ile)	Max	Mean	SD	CV (%)
Feb (days)	0	0	1	3.5	13	2.5	3.1	121.4
Mar (days)	0	2	5	7	15	4.7	3.4	72.8
Apr (days)	0	4	6	8	10	5.9	2.5	42.6
May (days)	0	3	5	8.5	15	5.8	3.9	67.6
Jun (days)	1	5.5	7	9	15	7.1	3.2	44.8
July (days)	7	13	14	17	21	14.9	2.9	19.5
Aug (days)	9	14	16	17	21	15.6	2.5	15.8
Sep (days)	7	10	11	12	17	11.1	2.2	19.6

Table 10: Descriptive statistics of monthly total rainfall for FMAM and JJAS seasons

Months	Min	Quartile 1 (25%ile)	Quartile 2 (Median)	Quartile 3 (75%ile)	Max	Mean	SD	CV (%)
Feb (mm)	1.1	9.6	26.8	52.6	131.6	37.3	36.6	98.2
Mar (mm)	2.4	26.2	46.4	85.4	151.8	58.3	38.8	66.6
Apr (mm)	10.3	36	48.3	70.8	173.8	57.3	36.3	63.4
May (mm)	1.2	18.3	45	84.9	203.8	56.6	47.8	84.5
Jun (mm)	1.8	32.4	60.9	101.65	210.9	68.6	44.3	64.5
Jul (mm)	71.3	139.65	187.9	247.9	429.4	198.8	80.5	40.5
Aug (mm)	86.3	150.1	179.5	225.9	324.8	187.8	54.1	28.8
Sep (mm)	33.3	65	86.4	128.2	199.9	97.1	40.6	41.8

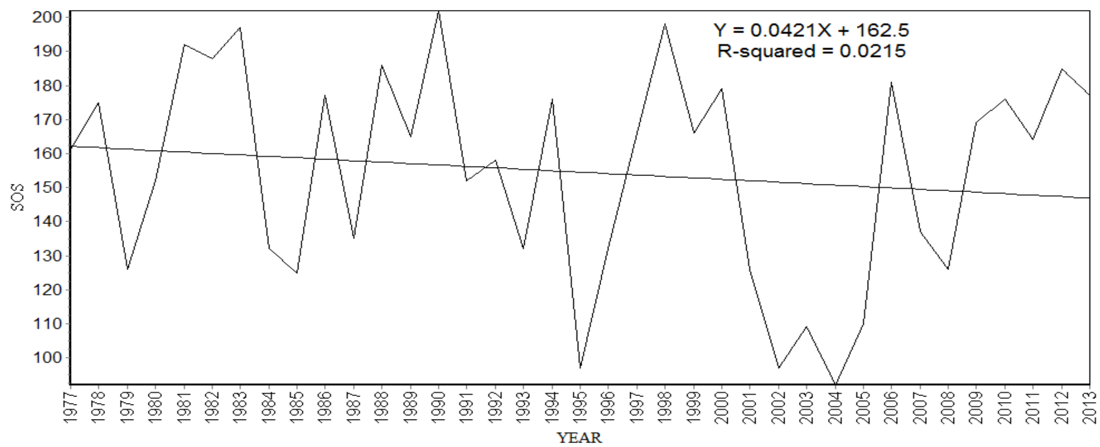

Figure 141: Variability of start of the rainfall season (Onset) over 1977-2013 period taking 1st April as potential start of the season.

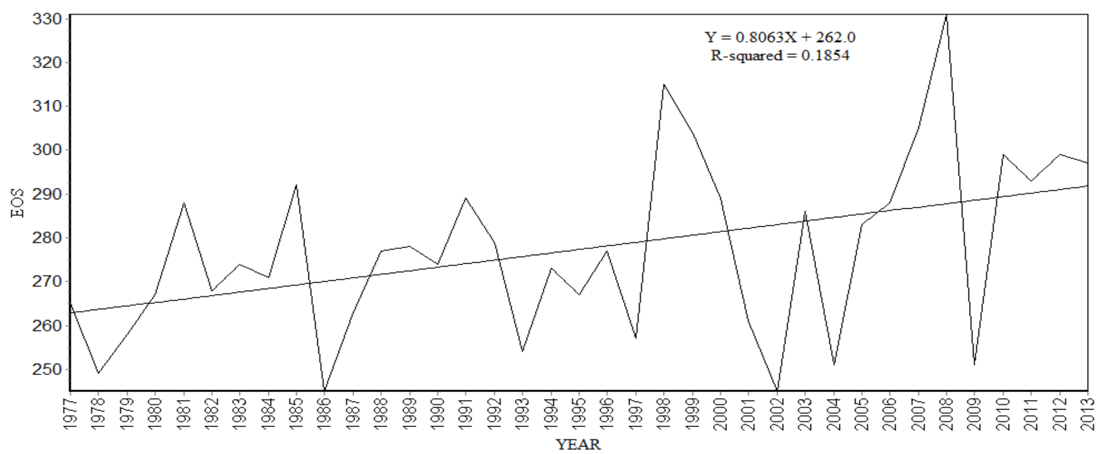

Figure 15: Variability of end of the rainfall season (Cessation) over 1977-2013 period taking 1st September as potential end date**.**

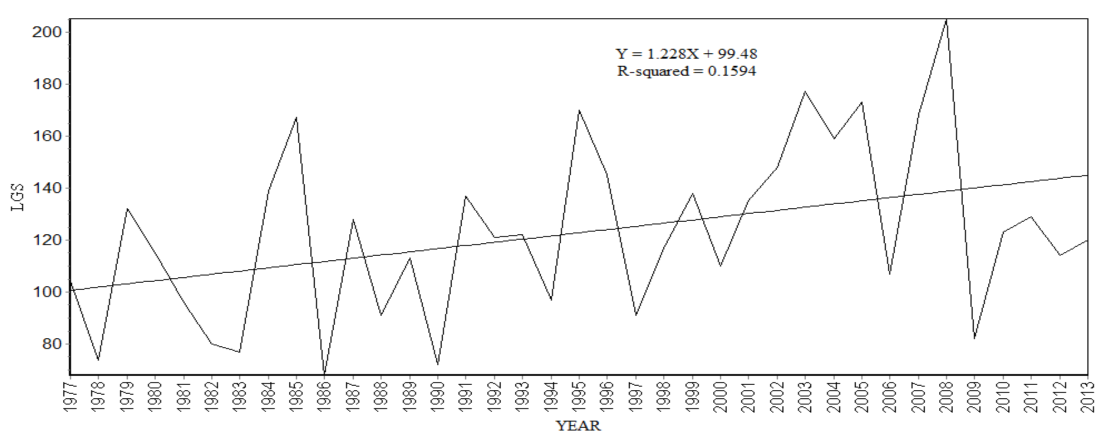

Figure 16: Variability of length of growing season over 1977-2013 period

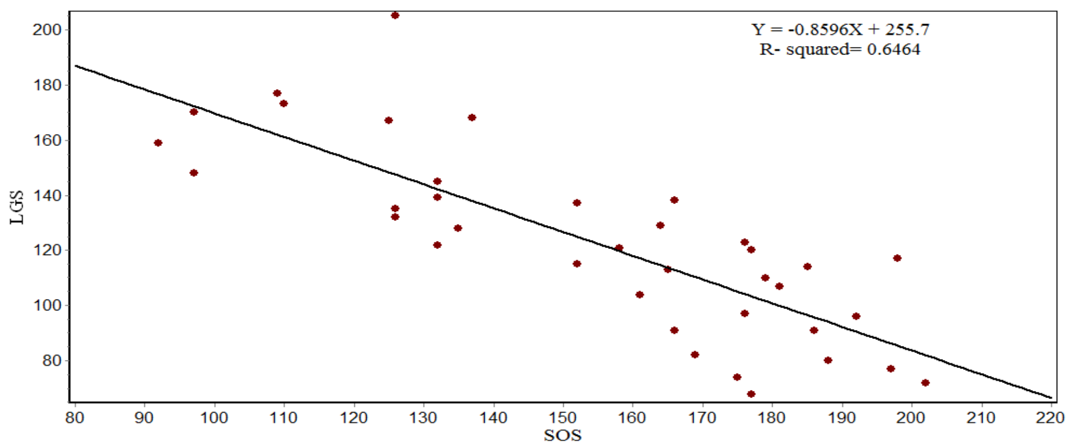

Figure 17: Correlation between LGS and SOS over 1977-2013 period.

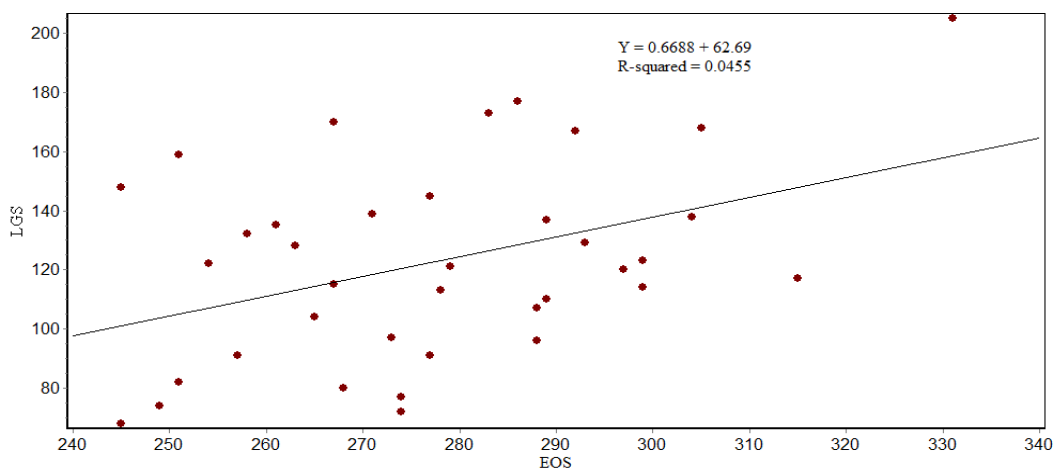

Figure 18: Correlation between LGS and EOS over 1977-2013 period.

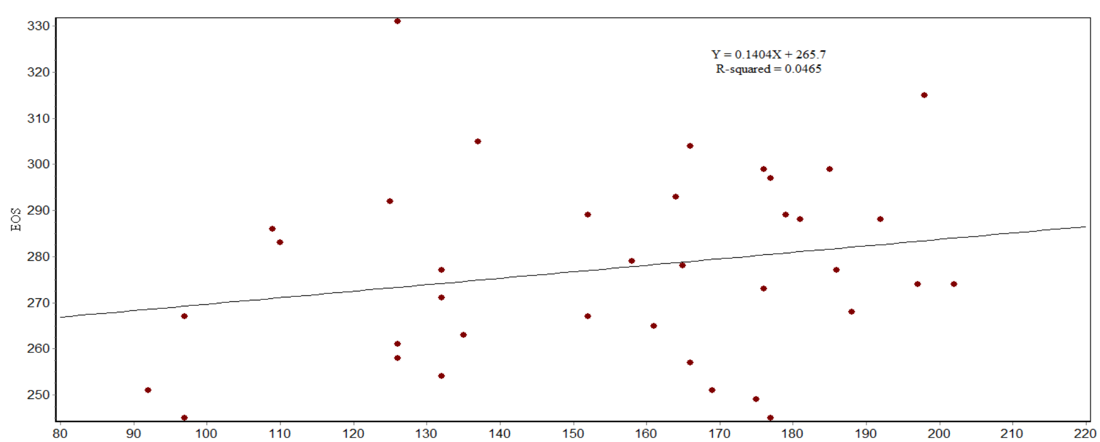

Figure 19: Correlation between EOS and SOS over 1977-2013 period.

4.6.5. Probability of dry spell length

To provide important decision tool to farmers, different dry spell lengths were examined. Accordingly, given a condition that 1st of April is a potential planting date, the probability of dry spells longer than 7, 10 and 15 days were analyzed (Figure 20). This sheds light into the risks related to a range of dry spell lengths during the entire rainy season. The probability of occurrence of longer dry spells (longer than 15 days) is 0·27 in April and decreases to 0 from end of June to end of July and increases again after the end of August (Figure 20). The probability of dry spells of 7 and 10 days is 0.9 and 0.65 during the earlier months respectively. The 10 and 15 dry spell probability curves converge to their minimum during the peak rain season (Days 184–200) while the 7 dry spell probability curve gets closer to zero and increases again around September (Days 245–274), signaling the end of the growing season. In general, the *Belg* (short rain season) has higher probability of dry spells than the *Kiremt* (main rain season). According to Stern and Coe (1984), the intermittent dry spell becomes critical in rainfed farming particularly for the seedling establishment during the first 30 days or so after planting. In fact, a dry spell of any length could occur at any stage of crop growth; however, it is potentially damaging if it coincides with the most sensitive stages such as flowering and grain filling.

Information on the probability of such a range of dry spell lengths is useful for different groups of farmers who work under different capability or resource endowments. For instance, farmer ‘A’ (a risk taker) who may have access to irrigation water or have a crop adapted to suspend its growth under a longer dry spell could decide to plant during the earliest /risky months of the growing season. In this way, one can maximize outputs by taking risks associated with such a long dry spell. On the other hand, a resource poor farmer ‘B’ (a risk averse) lacking water resources or other soil water management techniques or decision tools to manage any risk of dry spell longer than 7 or 10 days has to wait until the sufficient soil water accumulates (Girma, 2005).

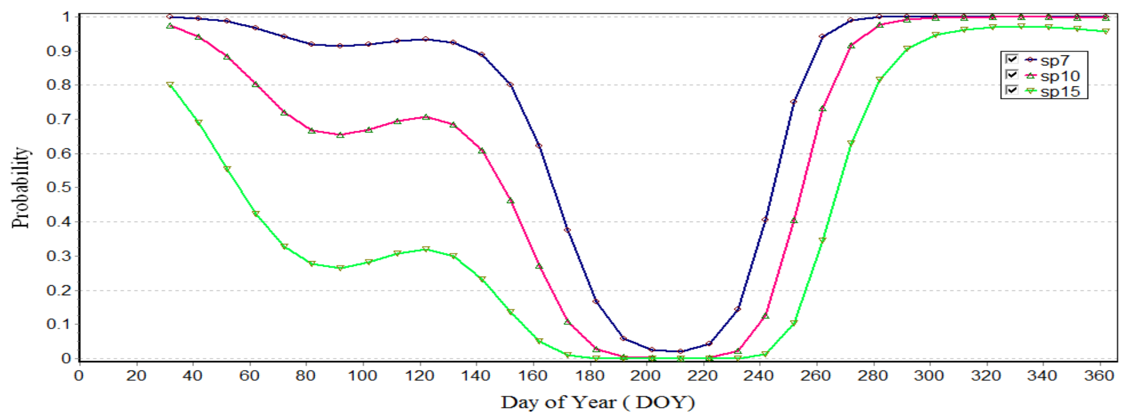

Figure 20: Probability of dry spells longer than 7, 10 and 15 days, given 1st of April as potential start of the season at Adulala watershed, Central Rift Valley of Ethiopia

4.7. Rainfall-Runoff Analysis for Rainwater Harvesting

4.7.1. Design rainfall of the area

In the case of irrigation, the design rainfall is the dependable rainfall which is 80% probability of exceedance (FAO, 1992). In this study, the annual design rainfall at 80% probability of exceedance was found to be 656 mm while the average monthly design rainfall was 54.67 mm respectively (Appendix Table 1 and Figure 21).

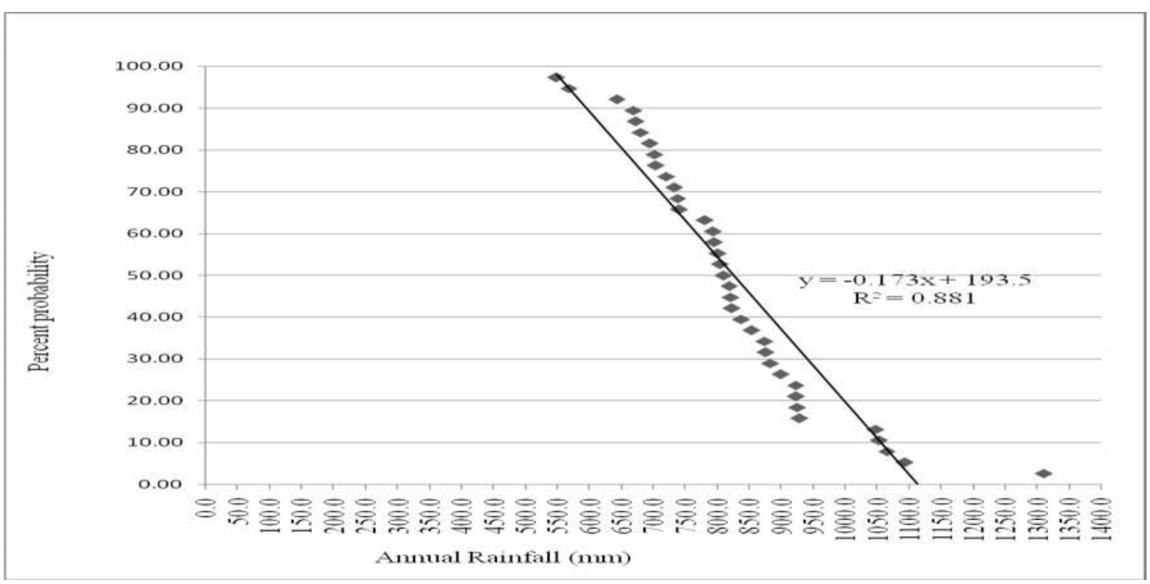

Figure 21: Dependable annual design rainfall at 80% probability of exceedance

4.7.2. Design runoff harvested

By using the data of soil classification and infiltration rates, the catchment for a sub watershed in Adulala was classified into hydrological soil groups A with high infiltration rate (>8) mm/hr under excessive drained sand and gravel category according to USDA-SCS, (1964) (Appendix Table 2).

Based on SCS model (Eq. 9) and using a CN- value of 36 under hydrologic soil group A (Appendix Table 5) and a monthly average 80% dependable design rainfall of 54.67mm, an average monthly and annual surface runoff were found to be 3.05 and 36.6 mm respectively. Since there were no runoff observations available from Adulala watershed, the results could not be compared with the measured values.

4.8. Crop Water Requirements

4.8.1. Reference evapotranspiration

Monthly averaged daily reference evapotranspiration (ET_o) for 37 year period (1977-2013) were calculated. Appendix Table 4 shows ET_o results as well as long term monthly averaged daily ET_o obtained at 80% probability. Using the monthly averaged daily ET_o values at 80% probability of exceedance, the annual reference evapotranspiration was estimated at 2121.29 mm per year. Similarly Yenesew (2015) reported an annual evapotranspiration of 1994 mm for the period of 1977 to 2012. The mean annual rainfall (820 mm per year) as given in Appendix Table 6 was lower than the reference crop evapotranspiration by a short fall of nearly 1301.29 mm per year. The maximum mean monthly reference crop evapotranspiration was 208.63mm i.e. equivalent to 6.73 mm per day and happened in the month of March and the minimum value was found during the month of September with a mean value of 141.6 mm per month (4.72mm/day).

4.8.2. Crop evapotranspiration (ET_c)

Table 11 shows summaries of crop water requirement and irrigation requirements as well as cultivated area and the total available storage capacity for the 31 farmers. Appendices 7- 13, show crop water requirements and irrigation requirements for individual crops. The results show that planting *teff* with a growing period length of 90 days would have a CWR of 473 mm while requiring a supplementary irrigation depth of 91.5 mm. A maize variety with a growing period of 125 days to maturity would require 547.1mm depth, while 168.6 mm would be required as supplementary irrigation depth. Similarly, a wheat variety of 90 days would need 414 mm as CWR and 55.3 mm supplementary irrigation. Dry beans of 90 days growth period would have a CWR of 425.6 mm while 66.8 mm being supplementary irrigation. Citrus crops with a growing period of 365 days would have a CWR of 1611.4 mm of which 1152.5 mm being irrigation supplement required. Small vegetables with 95 days growth period would need 468.7mm as crop water requirement with 102 mm being irrigation supplement required, while large vegetables with growth period of 120 days would have a crop water requirement of 587.5 mm of which 216.4 mm being supplementary irrigation depth.

Considering irrigation volume, a total of 3285.9 m^3 is required as supplementary irrigation for all the major crops grown in the area during dry spells for an individual farmer. However, supplementary irrigation for all crops is not possible with the current storage capacity as most of the 31 farmers have one storage tank with a capacity of 90 m^3. This entails that lack of supplementary irrigation during dry spells would result in reduced crop yield as the crop does not reach its physiological potential. On the other hand small vegetables could be supplemented as their required irrigation volume of 86.7 m^3 is lower than the available storage capacity. More storage tanks are thus required in order to harvest more runoff which goes to worst due to limited storage in the area.

Table 11: Summary for crop water requirements and irrigation requirements for major crops in Adulala watershed

Crop type	Length of growth period (days)	Crop water requirement (mm)	Net Irrigation requirement (mm)	Cultivated area (m^2)	Irrigation volume (m^3)	Total available storage capacity (m^3)
Teff	90	473	91.5	4375	400	4340
Maize	125	547.1	168.6	4375	737.6	Same
Wheat	90	414	55.3	4375	242	Same
Dry beans	90	425.6	66.8	4375	292	Same
Citrus	365	1611.4	1152.5	1250	1441	Same
Small Vegetables	95	468.7	102	850	86.7	Same
Large vegetables	120	587.5	216.4	400	86.56	Same
Total				20000	3285.9	4340

4.9. Catchment to Command Area Rratio

Using equation 10 above, the catchment/command area ratio was estimated to be 8:1 in the study area. The commonest values are less than 10 but for macro catchments for runoff water harvesting systems this ratio may be in order of hundreds. This ratio is important in the design and planning of water harvesting systems. However, if required domestic water consumption should be considered when estimating the ratio. The ratio was based on CWR for individual crops, effective rainfall (Appendix Tables 7-13) and rainfall probability pattern of the area which gave 656 mm of rainfall as dependable rainfall at 80% probability considered for irrigation.

5. SUMMARY AND CONCLUSION

The study focused on potential rainwater harvesting technologies for improved crop production under climate variability in the study area through characterization of temporal variability of climate (rainfall and temperature), water harvesting structures, quantifying runoff in the watershed and estimation of crop water requirements for major crops in the watershed in order to establish the possibility of supplementary irrigation for major crops.

A field survey was conducted to identify the existing water harvesting structures, agricultural practices and associated activities in the watershed. A well-structured questionnaire was developed to obtain important data which included household size, livestock size, size of farm land, types of crops grown, and date of planting, and production constraints. Descriptive statistics were used to describe such as percentages, mean, standard deviations and tests of significance were employed in the process of comparing socio-economic and institutional characteristics of the household in the watershed.

Climatic events which comprised of SOS, EOS, LGS, probability of dry spells and number of rain days were characterized from long-term climatic data (1977-2013) using INSTAT (v 3.36) statistical software. Data quality control and homogenization were performed using RClimdex 1.0 and RHtestV4 software while monthly ET_o values from the long-term meteorological data were computed for each year using Penman-Monteith method in CROPWAT 8.0 for windows. The reference evapotranspiration obtained at 80 percent probability levels were used to estimate crop water requirement for economically important crops in the area.

Soil samples were collected at three depths (0 – 20, 20 - 40 and 40 – 60 cm) from the sub watershed area, garden and main fields for laboratory analysis of selected physical and chemical properties of the soil which included; particle size distribution, field capacity, permanent wilting point, available soil moisture, total nitrogen, phosphorus, organic matter and soil pH of which physical parameters saved as input data in the CROPWAT software for estimation of CWR were as chemical parameters provided as reference for introducing new crops in the area that would be of economical value .Standard laboratory methods were used to determine important soil properties.

The USDA- SCS rainfall-runoff model with data on existing land use, soil, topography, and tabulated value corresponding to these natural features were used in estimating the amount of runoff that could be generated on the basis of a given surface features. The hydrologic soil group and the existing land use were used to estimate a CN (Curve Number) for the catchment which was used to estimate the maximum soil retention potential (S). The catchment/command area ratio was determined using the relationship between crop water requirements, design rainfall at 80% probability of exceedance, effective rainfall at 80% probability of exceedance of the dependable design rainfall and runoff coefficient.

The study showed that as at December 2014, Adulala has 923 Households on which only 31 farmers have water harvesting structures and a total population of 4,722. Farmers have cattle, donkey, goat, sheep and chicken (local and cross bred). The average land holding in the watershed was 1.75ha. The survey results indicated that farmer's awareness about water harvesting among others was high in the watershed. However, the use of these technologies is still at lower level due to financial constraints. The watershed has a total area of 2747.7 Hectares and 38 water harvesting structures of which 34 are hemispherical in shape with a storage capacity of 90 m^3 each while 4 are rectangular with a storage capacity of 320 m^3 hence bringing the total storage volume to 4340 m^3. Both the hemispherical and rectangular tanks are lined with cement. Runoff from the sub watershed is conveyed to the tanks through open earthen channels. However, a lot of runoff is lost through seepage. A rectangular type silt trap is constructed at 3 m from the storage tank under Ethiopian conditions. Major crops grown in the watershed during the main season include; maize, *teff*, beans and wheat, while minor crops include; onion, tomato, cabbage, coffee, pepper, cassava and chill. Also planted around the homestead are orchard crops which include; orange, mango, and lemon. Soil pH results ranged from7.08 to 7.82 in the garden fields (field 1) around the homestead and 7.35 to 8.03 in the main fields (field 2). In general, the soil pH in the watershed represents a slight alkaline condition.

Adulala watershed has a bimodal rainfall pattern with a mean annual rainfall of 820 mm. The inter annual rainfall variability showed a significant ($p<0.05$) increasing trend of 1.863 mm per year while the JJAS season equally showed a significant but highly increasing trend at a rate of 3.678 mm per year. The FMAM season shows a non significant decreasing trend of -1.246 mm per year. The watershed has a mean annual maximum temperature of 28.75 Degrees Celsius and a mean annual minimum temperature of 13.87 Degrees Celsius based on the long term temperature data. However, the temporal variability of maximum temperature showed less variability at a lower rate though the changes are highly significant during the 30 years time period.

The earliest potential onset date of the growing season is day 92 (1st April) and the latest is day 202 (20th July). The variability in the start of the season is non significant while increasing at a decreasing trend of 0.0421 days per year. The main rainy season terminates during the last days of September (262 DOY) once in four years time and terminates earlier than 290 DOY (2nd week of October) in three out of four years while the earliest possible end date of the growing season is day 245 (1st September). The probability of occurrence of longer dry spells (longer than 15 days) was 0. 27 in April and decreases to 0 from end of June to end of July and increases again after the end of August while, the probability of dry spells of 7 and 10 days was 0.9 and 0.65 during the earlier months respectively.

The annual design rainfall at 80% probability of exceedance was found to be 656 mm while the average monthly design rainfall was 54.67 mm respectively while average monthly and annual surface runoff were found to be 3.05 and 36.6 mm. Total irrigation volume required to supplement both major crops and vegetables was found to be 3285.9 m^3.

The study has established that rainfall and temperature in the study area have been decreasing and increasing, respectively, negatively affecting the production and management of different crops. Different forms of changes on rainfall have been identified including shrinking of start of the rain season, length of the growing season, end of the season and number of rain days. The analysis and perception of the local people indicated shift on the onset of long rains from June to July with shortening of rainfall period. The study has also shown that the watershed has the potential for runoff generation which could help meet crop water requirements in the area. A combination of strategies to adapt alongside ex-situ water harvesting, such as proper timing of agricultural operations, crop diversification, use of improved crop varieties, changing planting dates, increased use of water and soil conservation techniques do exist. However, such measures need to be strengthened and ensure that each farmer should have at least a water harvesting tank for supplementary irrigation for important crops during intermittent dry spells within the rainy season and full irrigation during the dry season for high value crops that increases farmers' income and thereby improving the livelihood. Use of drip irrigation should be encouraged as it has high application efficiency, higher yield and ensures high quality crops.

The study also makes the following recommendations;

Open earthen canals that convey runoff to the storage tanks should be lined with concrete to reduce seepage losses.

Farmers should be persuaded to ensure that silt traps are constantly desilted as it does not require funds.

There is need to replace damaged roofing materials on the storage tanks to reduce evaporation loses.

Supplementary irrigation for small vegetables could be encouraged with the current storage volume of $90m^3$ per farmer as it is higher than the required irrigation volume of $86.7m^3$.

Each farmer in the watershed should have at least one water harvesting pond to ensure and improve the livelihood and avoid risk of climate variability.

Relevant government institutions should ensure that weather forecasting information reaches farmers for them to make informed decisions pertaining to agricultural production such as choices of early maturing varieties among others.

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7.0. APPENDIX

Appendix Table 1: Rainfall probability analysis

Years	Annual Rainfall	Years	Ranked Rainfall	m= 1	P %= (m/n+1)	T=(100/P)
1977	1310.4	1977	1310.4	1	2.63	38.0
1978	672.4	2010	1093.1	2	5.26	19.0
1979	875.7	2007	1064.7	3	7.89	12.7
1980	668.6	2008	1052.7	4	10.53	9.5
1981	800.3	1998	1046.9	5	13.16	7.6
1982	739.7	2006	928.6	6	15.79	6.3
1983	817.6	2012	924.7	7	18.42	5.4
1984	567.6	1991	923.5	8	21.05	4.8
1985	795.5	2013	922.1	9	23.68	4.2
1986	642.3	2003	899.0	10	26.32	3.8
1987	694.6	2005	882.4	11	28.95	3.5
1988	703.9	1979	875.7	12	31.58	3.2
1989	702.2	1993	873.7	13	34.21	2.9
1990	719.7	2000	853.5	14	36.84	2.7
1991	923.5	1996	836.9	15	39.47	2.5
1992	780.8	2004	822.5	16	42.11	2.4
1993	873.7	2001	820.6	17	44.74	2.2
1994	737.5	1983	817.6	18	47.37	2.1
1995	733.4	2011	810.1	19	50.00	2.0
1996	836.9	1997	804.0	20	52.63	1.9
1997	804.0	1981	800.3	21	55.26	1.8
1998	1046.9	1985	795.5	22	57.89	1.7
1999	793.1	1999	793.1	23	60.53	1.7
2000	853.5	1992	780.8	24	63.16	1.6
2001	820.6	1982	739.7	25	65.79	1.5
2002	548.7	1994	737.5	26	68.42	1.5
2003	899.0	1995	733.4	27	71.05	1.4
2004	822.5	1990	719.7	28	73.68	1.4
2005	882.4	1988	703.9	29	76.32	1.3
2006	928.6	1989	702.2	30	78.95	1.3
2007	1064.7	1987	694.6	31	81.58	1.2
2008	1052.7	2009	679.4	32	84.21	1.2
2009	679.4	1978	672.4	33	86.84	1.2
2010	1093.1	1980	668.6	34	89.47	1.1
2011	810.1	1986	642.3	35	92.11	1.1
2012	924.7	1984	567.6	36	94.74	1.1
2013	922.1	2002	548.7	37	97.37	1.0

Appendix Table 2: Criteria for classifying soils into hydrologic soil group

Hydrologic soil group	Runoff potential	Infiltration Rate	Typical soils
A	Low	High(>8mm/hr)	Excessive drained sand and gravel
B	Moderate	Moderate (4-8mm/hr)	Medium textures
C	Medium	Slow (1-4mm/hr)	Fine texture or soils with a layer impending downward drainage
D	High	Very slow (<1 mm/hr)	Swelling clays, clay pan soils over impervious layers

Source :(USDA-SCS 1964)

Appendix Table 3: Type and capacity of water harvesting structures in Adulala watershed

S/N	Description	Qty	Formula (volume)	Dimensions (m)	Total capacity (m3)
1	Hemispherical	34	$V=\frac{2}{3}\pi r^3$	Diameter = 7 Depth = 3.5	3060
2	Rectangular	4	lbh	L = 8 W = 8 H = 5	1,280
	Total				4340

Appendix Table 45: Monthly averaged daily evapotranspiration (ET_o) 1977- 2013

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1977	4.08	3.74	4.85	5.22	4.76	4.31	4.31	3.89	3.59	3.83	4.56	4.40
1978	5.54	4.61	5.46	6.22	5.42	6.40	4.86	4.32	4.31	5.29	6.26	5.44
1979	4.61	5.69	5.94	6.75	5.55	5.56	4.40	4.39	4.34	5.29	5.97	5.50
1980	5.12	6.57	7.00	6.55	6.75	5.80	4.60	4.61	4.49	5.38	6.40	5.75
1981	6.54	6.08	4.50	4.91	6.53	6.95	4.80	4.41	4.07	5.47	5.89	5.57
1982	5.09	5.00	6.74	5.72	5.77	6.39	5.06	4.16	4.19	4.47	4.33	4.45
1983	5.01	5.43	5.71	5.37	5.15	5.57	5.16	3.94	4.33	4.94	5.63	5.13
1984	5.69	6.74	7.46	8.29	5.64	5.55	5.11	4.75	4.50	6.70	6.27	5.63
1985	5.97	6.61	7.22	5.13	5.62	6.42	4.45	4.16	4.55	5.55	6.01	5.71
1986	5.82	4.62	5.70	5.13	6.09	5.29	4.65	4.72	4.63	5.32	6.05	5.59
1987	5.83	5.94	4.96	5.65	5.28	5.64	5.68	4.49	4.91	5.30	5.65	5.56
1988	5.06	5.82	6.87	5.48	6.75	5.90	4.35	4.40	4.42	4.33	5.47	5.10
1989	5.01	5.41	5.55	5.55	6.57	6.30	4.68	4.42	4.36	5.08	5.43	4.82
1990	5.38	4.12	5.05	4.98	6.13	6.43	5.01	4.55	4.15	5.14	5.30	5.32
1991	5.35	5.39	5.77	6.08	6.00	5.96	4.25	4.31	4.83	5.74	5.44	4.76
1992	4.42	5.07	6.56	5.94	6.19	6.14	4.92	4.50	4.80	5.15	5.47	5.05
1993	4.62	4.69	6.58	5.37	5.30	5.57	4.58	4.75	4.28	4.99	5.68	5.54
1994	5.88	6.08	6.24	6.11	6.15	5.75	4.52	4.25	4.40	5.45	5.17	5.33

Appendix Table 4: (Continued)

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1995	5.50	5.89	5.50	5.07	5.92	6.47	5.03	4.74	4.52	5.77	5.41	5.59
1996	5.10	6.42	5.69	5.48	4.60	4.42	5.15	4.55	4.24	5.14	5.32	5.37
1997	4.77	6.54	6.42	5.51	6.33	5.60	4.45	4.33	4.77	4.57	4.79	5.24
1998	4.53	5.28	5.59	6.45	6.06	6.57	4.99	4.29	4.25	4.41	5.11	5.30
1999	5.45	6.81	5.11	6.85	6.54	5.99	4.39	4.51	4.53	4.20	5.43	5.45
2000	5.87	6.35	6.91	6.20	5.66	6.16	4.60	4.45	4.07	4.42	4.91	5.17
2001	4.92	6.05	4.78	6.53	5.68	5.60	5.29	4.43	5.40	6.70	6.12	5.78
2002	5.18	6.56	5.89	6.42	6.45	6.51	5.92	4.83	4.74	6.39	6.28	4.73
2003	5.21	6.09	6.29	5.58	6.76	5.88	4.37	4.00	4.31	6.19	6.42	5.30
2004	5.07	6.14	6.13	5.29	7.06	6.19	4.82	4.63	4.81	5.28	5.65	5.28
2005	4.97	6.54	6.10	6.49	4.93	5.73	4.61	4.89	4.52	5.99	5.90	6.03
2006	5.80	6.20	5.62	5.28	6.09	5.90	4.70	4.08	4.42	5.12	5.82	4.74
2007	4.85	5.62	6.57	5.64	6.21	5.45	4.73	4.07	4.39	5.40	5.92	5.61
2008	5.66	6.65	7.20	6.69	5.71	5.89	4.76	4.41	4.76	5.37	4.90	5.08
2009	4.79	6.50	7.23	6.13	6.70	6.58	5.26	4.57	5.55	5.36	5.88	4.87
2010	5.51	5.59	5.51	5.37	5.09	5.71	4.41	4.08	4.30	5.59	5.18	4.80
2011	5.14	6.74	6.7	6.56	5.86	5.71	4.76	4.18	4.02	5.57	4.77	5.17
2012	5.4	6.52	6.65	5.41	6.29	6.03	4.08	3.72	4.09	5.35	5.44	5.11
2013	4.81	6.34	5.93	5.52	5.73	5.7	4.36	4.31	4.61	4.88	5.19	5.3
Aver.	5.23	5.85	6.05	5.86	5.93	5.89	4.76	4.38	4.47	5.27	5.55	5.26
80% Prob	5.65	6.56	6.73	6.45	6.47	6.26	5.08	4.62	4.72	5.67	6.02	5.59

Appendix Table 5: Estimation of runoff curve numbers (CN); (from USDA-SCS 1964)

Land use or cover	Treatment or practice	Hydrologic condition	Hydrologic soil group			
			A	B	C	D
Fallow	Straight row	-	77	86	91	94
Row crops	Straight row	Poor	72	81	88	91
	Straight row	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	Contoured	Good	65	75	82	86
	Terraced	Poor	66	74	80	82
	Terraced	Good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
	Straight row	Good	63	75	83	87
	Contoured	Poor	63	74	82	85
	Contoured	Good	61	73	81	84
Pasture or range	Straight row	Fair	39	61	74	80
	Straight row	Good	47	67	81	88
	Contoured	Poor	25	59	75	83
Woods (farm wood lots and Shrubs)		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77

Appendix Table 6: Annual monthly rainfall (mm) 1977 – 2013.

Month Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1977	97.5	4	63.6	175.6	70	211.8	129.2	153.6	86.4	261.6	53.4	0	1307
1978	2.5	269	4.7	48.7	12.5	51.1	87.8	177.6	72.5	47.7	0	34.8	809
1979	59.4	13.4	60.4	14.1	75	129.9	225.8	142.6	87.4	21.6	0	14.8	844
1980	19.5	0	7.4	29.3	25.5	95.3	190.7	181.3	93.4	47.6	4.1	0	694
1981	0	62.9	134	65.9	1.2	4.5	249.6	150.8	129.6	10.5	8.1	0	817
1982	10.8	24.3	10.3	24.5	51.5	30.4	135.2	228.1	31.6	68.5	88.1	7.1	710
1983	0	35.8	56	40.4	130	37.9	175.2	137.2	155.1	10.3	0	1.3	779
1984	0	0	14	18.4	70	21.2	154.8	153.2	97.3	11	0.9	15.9	557
1985	6.2	49.5	14.1	44.5	81	42.9	280.3	261.7	76.7	2.7	0	0	860
1986	0	9.2	67.6	78.8	25.6	92.2	148.6	90	67.7	11	0	2.9	594
1987	0	23.4	88.5	6	120	51	102.4	228.1	121.1	2.7	0	0	743
1988	35.4	16.7	2.4	57.3	22	54	188.8	186.3	71	14	0	4.5	652
1989	0	102.7	35.1	66.7	1.8	53.1	148	272.2	94.1	11.2	0	6.6	791
1990	0	47.3	59.1	54.3	12.2	35.2	127.1	222.3	115.8	13.8	0	0	687
1991	0	9.4	110.6	23.4	50	157.6	235.6	235	76.7	8	0	1.8	908
1992	5.5	45.5	0	39.3	10.7	78.6	153.8	247.1	65.4	47.2	3.6	57.6	754
1993	40.2	0	0	154.6	60	60	250.6	125.6	76.4	39.7	10.9	10.8	829
1994	0	29.3	35.8	88.6	25	73.8	307.6	88.1	121.9	21.1	8	22.6	822
1995	0	0	73	52.7	9.9	128.3	158.8	193.5	134.4	2.2	1.5	13.5	768
1996	26.5	19.2	151.8	66.7	71.3	112	124.9	166.6	74.8	0	6.8	0	821
1997	14.1	37.5	46.1	37.8	3.2	14.7	231	153.9	75.1	140	11.9	0	765
1998	16	0	51.4	14.3	40.3	76.8	257.1	325.7	78.4	132.1	0	0	992
1999	7.6	6.8	20.9	14.5	3.1	83.2	248.8	176.9	54	146	43.4	1.8	807
2000	0	0.9	8.5	37.1	77.5	159.7	263.2	180.2	73.1	80.6	0.9	16.9	899
2001	0	9	97.2	72	80	22.2	221.4	161.6	44.6	1.4	1.6	11.6	723

Appendix Table 6: (Continued)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Year													
2002	42.9	26	58.2	66.7	49.5	30.1	74.9	157.7	131.4	5.9	1.8	21.1	666
2003	17.5	0	128.1	78.6	5.8	74	190.2	187.5	140.2	1.8	20.3	54	898
2004	51.6	46.9	93.7	74.7	1.8	47.9	203.5	140	121.9	67.9	12.1	4.5	866
2005	23	40.7	85	123.7	90	99.6	117.8	232.2	147	4.7	0	0	964
2006	11	0	59.4	88.2	34.7	62.1	209.4	217	200.1	24.2	9.7	34.3	950
2007	48.5	2.8	74.8	73.7	75	45.8	171.2	238.7	122.7	30.5	74.7	0	958
2008	0	120	0.7	51.2	60.2	51.9	334.3	210.9	58.6	92.5	1.3	0	982
2009	53	1.5	0	28.2	52.9	107.1	151.9	138.8	132.1	99.8	16.5	47.9	830
2010	0	0	89.9	48.1	95	102	210.2	294.4	183	0	40.6	3.2	1066
2011	0	0	37.9	71.9	38.2	22.4	126.4	218.2	225.1	0	5.3	0	745
2012	0	0	47.5	17	18.3	71.6	430.8	209.9	30.7	3	10.2	0	839
2013	2	0	66.6	0	21.4	0	399	122.3	0	30.6	0	0	642
Aver.	16	28	53	55	45	70	200	189	99	41	12	11	820
80%prob	24.9	37.4	92.5	80.3	78.4	105.3	259.1	234.5	0	67.3	13.9	27.6	-

Appendix Table 7: Crop water requirement for *Teff*

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jun	1	Init	0.6	3.84	38.4	14.5	23.9
Jun	2	Deve	0.7	4.42	44.2	15.3	28.9
Jun	3	Deve	0.96	5.68	56.8	30.6	26.2
Jul	1	Mid	1.17	6.38	63.8	51.9	11.9
Jul	2	Mid	1.18	6	60	67.8	0
Jul	3	Mid	1.18	5.82	64	63.4	0.6
Aug	1	Late	1.18	5.63	56.3	61.3	0
Aug	2	Late	1.08	5.01	50.1	61.3	0
Aug	3	Late	0.94	4.38	39.4	33.5	0
Total					473	399.5	91.5

Appendix Table 8: Crop water requirement for Maize

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jun	1	Init	0.3	1.92	19.2	14.5	4.7
Jun	2	Init	0.3	1.91	19.1	15.3	3.8
Jun	3	Deve	0.46	2.7	27	30.6	0
Jul	1	Deve	0.74	4.04	40.4	51.9	0
Jul	2	Deve	1.02	5.18	51.8	67.8	0
Jul	3	Mid	1.26	6.22	68.4	63.4	5
Aug	1	Mid	1.29	6.15	61.5	61.3	0.3
Aug	2	Mid	1.29	5.95	59.5	61.3	0
Aug	3	Mid	1.29	6	66	40.9	25.1
Sep	1	Late	1.2	5.63	56.3	0.1	56.2
Sep	2	Late	0.9	4.24	42.4	0	42.4
Sep	3	Late	0.58	2.94	29.4	0	29.4
Oct	1	Late	0.38	2.04	6.1	2.6	1.8
Total					547.1	409.7	168.6

Appendix Table 9: Crop water requirement for Wheat

Month	Decade	Stage	Kc Coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jun	1	Init	0.3	1.92	19.2	14.5	4.7
Jun	2	Deve	0.45	2.87	28.7	15.3	13.4
Jun	3	Deve	0.87	5.14	51.4	30.6	20.8
Jul	1	Mid	1.2	6.55	65.5	51.9	13.6
Jul	2	Mid	1.22	6.21	62.1	67.8	0
Jul	3	Mid	1.22	6.02	66.2	63.4	2.8
Aug	1	Late	1.22	5.81	58.1	61.3	0
Aug	2	Late	0.92	4.26	42.6	61.3	0
Aug	3	Late	0.48	2.25	20.3	33.5	0
Total					414	399.5	55.3

Appendix Table 10: Crop water requirement for Beans

Month	Decade	Stage	Kc Coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jun	1	Init	0.4	2.56	25.6	14.5	11.1
Jun	2	Deve	0.53	3.38	33.8	15.3	18.5
Jun	3	Deve	0.89	5.3	53	30.6	22.5
Jul	1	Mid	1.18	6.47	64.7	51.9	12.8
Jul	2	Mid	1.2	6.12	61.2	67.8	0
Jul	3	Mid	1.2	5.93	65.3	63.4	1.9
Aug	1	Late	1.2	5.73	57.3	61.3	0
Aug	2	Late	0.93	4.28	42.8	61.3	0
Aug	3	Late	0.52	2.42	21.8	33.5	0
Total					425.6	399.5	66.8

Appendix Table 11: Crop water requirement for Citrus

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jun	1	Init	0.7	4.48	44.8	14.5	30.3
Jun	2	Init	0.7	4.45	44.5	15.3	29.2
Jun	3	Init	0.7	4.15	41.5	30.6	11
Jul	1	Init	0.7	3.83	38.3	51.9	0
Jul	2	Init	0.7	3.56	35.6	67.8	0
Jul	3	Deve	0.7	3.45	37.9	63.4	0
Aug	1	Deve	0.7	3.36	33.6	61.3	0
Aug	2	Deve	0.71	3.28	32.8	61.3	0
Aug	3	Deve	0.72	3.34	36.7	40.9	0
Sep	1	Deve	0.72	3.4	34	0.1	33.9
Sep	2	Deve	0.73	3.45	34.5	0	34.5
Sep	3	Deve	0.74	3.72	37.2	0	37.1
Oct	1	Deve	0.74	3.98	39.8	8.7	31.2
Oct	2	Deve	0.75	4.26	42.6	13	29.6
Oct	3	Mid	0.76	4.38	48.2	8.7	39.6
Nov	1	Mid	0.76	4.48	44.8	0.1	44.7
Nov	2	Mid	0.76	4.57	45.7	0	45.7
Nov	3	Mid	0.76	4.46	44.6	0	44.6

Appendix Table 11: (Continued)

Month	Decade	Stage	Kc Coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Dec	1	Mid	0.76	4.35	43.5	1.7	41.8
Dec	2	Mid	0.76	4.24	42.4	2.5	39.9
Dec	3	Mid	0.76	4.27	47	2.2	44.7
Jan	1	Mid	0.76	4.3	43	1.6	41.4
Jan	2	Mid	0.76	4.33	43.3	1.2	42
Jan	3	Mid	0.76	4.54	50	2.2	47.8
Feb	1	Mid	0.76	4.76	47.6	2.4	45.2
Feb	2	Mid	0.76	4.98	49.8	2.7	47
Feb	3	Late	0.78	5.15	41.2	7.4	33.8
Mar	1	Late	0.81	5.4	54	14	40
Mar	2	Late	0.81	5.44	54.4	18.9	35.6
Mar	3	Late	0.81	5.37	59.1	17	42
Apr	1	Late	0.81	5.29	52.9	14.3	38.7
Apr	2	Late	0.81	5.22	52.2	13.1	39.1
Apr	3	Late	0.81	5.22	52.2	13	39.2
May	1	Late	0.81	5.23	52.3	12.4	39.9
May	2	Late	0.81	5.23	52.3	11.9	40.5
May	3	Late	0.81	5.18	57	14.6	42.4
Total					1611.4	590.5	1152.5

Appendix Table 12: Crop water requirement for Small vegetables

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jun	1	Init	0.7	4.48	44.8	14.5	30.3
Jun	2	Init	0.7	4.45	44.5	15.3	29.2
Jun	3	Deve	0.77	4.59	45.9	30.6	15.3
Jul	1	Deve	0.91	4.96	49.6	51.9	0
Jul	2	Deve	1.04	5.28	52.8	67.8	0
Jul	3	Mid	1.1	5.42	59.6	63.4	0
Aug	1	Mid	1.1	5.25	52.5	61.3	0
Aug	2	Late	1.1	5.08	50.8	61.3	0
Aug	3	Late	1.05	4.9	53.9	40.9	13
Sep	1	Late	1.01	4.72	14.2	0	14.1
Total					468.7	407	102

Appendix Table 13: Crop water requirement for large vegetables

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jun	1	Init	0.6	3.84	38.4	14.5	23.9
Jun	2	Init	0.6	3.82	38.2	15.3	22.9
Jun	3	Deve	0.64	3.78	37.8	30.6	7.2
Jul	1	Deve	0.8	4.38	43.8	51.9	0
Jul	2	Deve	0.98	4.96	49.6	67.8	0
Jul	3	Mid	1.15	5.69	62.6	63.4	0
Aug	1	Mid	1.21	5.78	57.8	61.3	0
Aug	2	Mid	1.21	5.6	56	61.3	0
Aug	3	Mid	1.21	5.64	62	40.9	21.1
Sep	1	Late	1.18	5.54	55.4	0.1	55.3
Sep	2	Late	1.04	4.93	49.3	0	49.3
Sep	3	Late	0.91	4.6	36.8	0	36.8
Total					587.5	407.1	216.4

Appendix 14: Questionnaire on water harvesting practices

Region:______________________ Zone ________________________

Woreda: _____________________ Farmer's Association:___________

Enumerator's Name: __________________________

Climate:Arid/Semi-arid/Sub-humid/humid:

____

Altitude: ____________masl. Latitude: _____________ Longitude: _____________

UTM reading: Easting: ___________________ Northing: ____________________

1. House hold demographic characteristics
    a) Name of household head___________________________________
    b) Sex-------------- Age--------------
    c) Spouse Name: ________________Sex: _________ Age: __________
    d) Size of HH:________________
        i. Male: _____________
        ii. Female: ___________
2. Experience in agriculture (in year): _____________________
3. Total farm size (as illustrate by respondent): ____________________

a) Land tenure

Farm land	Area	Remark
Owned		
Rent in		
Rent out		
Share in		
Share out		

b) Land use

	Area	Remark
Crop land		
Grazing land		
Fallow land		
Forest land		
Waste land		
Others		

4. Major soil types (as illustrate by respondent): ________________________

   a) Proportion of each soil type: 1. _______________ _________ %

   2. _______________ _________ %

   3. ______________ _________ %

   b) Indicate and rank the productivity of the soils from above mentioned:

   _____________________, ________________, _______________________

5. Livestock size:

   a) Oxen: _____ b) Cows: _____ c) Horses: ____d) Donkey: _____

   e) Chickens: ____f) Heifers: ___g) Calves: _____ h) goat: ___ Sheep:______

   h) Others (specify): ____

6. Major crops grown by season:

   a) Main season:

   ____

   b) Cool season:

   ____

7. Other house hold income (dairy, fattening, poultry, etc):

   ____

8. What is the major constraint for your agricultural production?

   ____

9. Is the annual agricultural production sufficient to meet the HH demand? Yes / No

10. What are your copping strategies when food crises happened to your family?

11. Do you have water source for human and animal consumption during the year? If no how do you manage the problem?

    ____

12. Have you ever heard, seen or engaged in WH technologies?

    a) If yes, what motivated you to adopt the technology?

    ____

    b) If no, what was the reason for not adopting the technology?

____

13. What storage type(s) are you using?

    a) Surface ponding – unlined or lined with plastic/cement/ or ___________
    b) Cistern – unlined or lined with plastic/stone/ cement/ or ___________
    c) Underground water – shallow/ deep well: _______________
    d) Rivers/streams/springs – diversion or micro dam
    e) Other specify:

    ____

14. If you are using surface or underground ponding, specify the shape of the pond? (spherical/hemispherical/dome/bottle/cylindrical/cone/rectangular)____________

15. What is the storage capacity of WHT?______________________________

16. Are you able to store the needed amount in the season? Yes/No __________

17. If no, give reason for not getting the required amount? ________________

    ____

18. For what purpose do you use the water (HH/livestock/farming)? _____________

    a) Give the proportion of water used for different purpose

        1. HH _______
        2. Livestock ________
        3. Irrigation __________
        4. Others, specify _________________________

19. If you use the water for irrigation, what type of crop(s) do you grow?

    ____

20. How do you use the harvested water for irrigation (as supplemental/full or both)?

    ____

21. Who owns and manage the WH structure(s) (community/Individuals etc.)?

    ____

22. What technique(s) do you use to abstract the water harvested?

    a) Treadle pump
    b) Rope and washer
    c) Hand pump
    d) Manual pump
    e) Motor pump
    f) Other(s) specify: ____

23. What are the major problem(s) for the method(s) of abstraction?

    ____

    ____

24. What was the reason for using the current water abstraction method(s)?

    ____

    ____

25. What problems, if any, do you have with storage tank? ____________________

    ____

26. What do you think the solution to the problem and the reason you could not solve it?____

    ____

27. Have you been sufficiently consulted by promoters when they started constructing WH schemes for you and others? What was your opinion?

____

____

28. What are possible water losses they encountered while they were using the pond?
29. What are the general benefits of water harvesting technologies?
30. What are the general undesirable effects of WH technologies?
31. What will you advise to reduce the undesirable effects?
32. Any other comments:

____

____

____