IMPACT OF SELECTED SOIL AND WATER CONSERVATION TECHNOLOGIES ON TREE SEEDLING SURVIVALS: A CASE STUDY IN GERDUBA WATERSHED, BORANA ZONE, ETHIOPIA

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STATEMENTS OF THE AUTHOR

First, I declare that, this is my original research work and all sources of materials used for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for M.Sc. degree at the Hawassa University, and open to use for the borrowers. This work has not been submitted to any other educational institution anywhere for the award of any academic degree, diploma, or certificate.

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He was born on November 11, 1987 G.C. in Oromia region, Horro Guduru Wollega Zone, Hababo Guduru Woreda. He attended his elementary and secondary school education in Kenate Biya Junior Secondary School and Fincha Senior Secondary School, respectively. He joined Mekelle University and graduated with B.Sc. Degree in "Soil Resources and Watershed Management" on July 09, 2011. From 2012 onwards, he has been working in Yabello *Woreda*, at Yabello Pastoral Dryland and Agricultural Research Center as the soil and water conservation and soil fertility improvement researcher as well as team leader. He has published **four** papers i.e. 1st on the proceeding of LCC-CRSP, 2nd Methods and Costs for Pond-Catchment Rehabilitation on the Borana Plateau, 3rd Enclosures for Rehabilitating Pond Catchments and Implications for Grazing Management on the Borana Plateau, 4th Outcomes of a Pastoral Sustainability Conference: The Borana People Must Better Manage Rangelands and Diversify Livelihoods for a Brighter Future.

DEDICATION

This thesis manuscript is dedicated to Christ Jesus, for nursing me with affection and love; my wife Adise Abosa, for her committed partnership in the success of my life; and my child Garumma, who sacrificed his love during my absence.

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LIST OF ACRONYMS

ANOVA	Analysis Of Variance
BoPRD	Bureau of Pastoralist and Rural Development
CDE	Center for Development and Environment
CEC	Cation Exchange Capacity
CV	Coefficient of Variation
EB	Ethiopian Birr
FAO	Food and Agricultural Organization
GIS	Geographical Information System
GPDI	Gayo Pastoral Development Initiative
GPS	Geographical Positioning System
Ha	Hectare
HH	Households
IRWH	*In-situ* Rainwater Harvesting
LSBE	Level Soil Bund Embankment
LSD	Least Significant Difference
NGO	Non-Governmental Organization
RCBD	Randomized Complete Block Design
SWC	Soil and Water Conservation
USDA	United States Department of Agriculture
WLRC	Water and Land Resource Center
YDPDO	Yabello District Pastoral Development office
YPDARC	Yabello Pastoral Dryland and Agricultural Research Center

ABSTRACT

Establishing forest plantation on degraded rangelands play a key role in forest rehabilitation processes through afforestation or/and reforestation. In-situ *rainwater harvesting has positive impact on seedling survivals at degraded rangelands. A quadrant of 10 m × 10 m of five times replication at three slope classes under area enclosure was used. Both survived seedlings and soil physical parameters were collected from three* in-situ *structures and three soil depths profiles (0-10, 10-20 and 20-30 cm) and then analyzed using T-test procedures in which LSD is used for mean comparison. The data generated from soil attributes were analyzed as 3x3 factorial experiment using GLM procedure; the selected SWC practices and soil depths were used as the two factors with three slope classes each, respectively. Of the transplanted seedling to the area enclosure with selected SWC structures namely, in pits (66.53, 46.13, and 25.66%), half-moon (66.53, 41.80, and 20.40%), and soil bund embankment (55.46, 42.60, and 28.80%) were survived at bottom, middle and upper slope classes respectively. The interaction of structures on conserving and storing moisture was not significant except level soil bund embankments. Because, tree seedlings rose at nursery site transplanted to the level soil bund embankment structures, that was, on the dig out soils. The conserved soil moisture is far from transplanted seedling roots as a result needs more energy to absorb but weak and short rooting system. Infiltration pits and half-moon showed good performance than level soil bund embankments at bottom parts. Grass regeneration and maintaining around* in-situ *rainwater harvesting devices as well as transplanted tree seedlings stay alive are excellent indicators of moisture availability. This explains that almost all* in-situ *structures play a crucial role at flat land rather than middle and upper parts but highest bulk density achieved for the upper parts, which might be due to risks of soil erosion and only left with very compacted cobles. Therefore, slope gradient have implication on* in-situ *rainwater harvesting devices efficiencies in conserving moisture for tree seedling survival so as to establish good forest stands.*

Keywords*:* Growth, in-situ rainwater harvesting, moisture stress, seedlings, survival.

1. INTRODUCTION

1.1. Background of the Study

Degraded vegetation, bush encroachment and erosion are generally visible symptoms of degraded rangelands (Mucina *et al*., 2003). Particularly, vegetation removal is a common phenomenon in most of the hilly tract causing land degradation (Arya *et al*., 2009). However, there are many approaches to degraded rangeland restoration. The time for restoration determined based on the selected approaches. The most suitable methods can largely be determined by soil type, climatic conditions, the causes and degree of rangeland deterioration and especially the degree of degradation (Tainton, *et al*., 2000).

Establishing forest plantation on degraded rangelands can play a key role in harmonizing long-term forest ecosystem rehabilitation process (Sharma and Sunderraj, 2005). The process of forest ecosystem rehabilitation can be accelerated through human intervention like afforestation or/and reforestation with moisture stress tolerant tree seedling transplanting from nursery sites in Dryland areas (Jha and Singh, 1992).

Afforestation is the common approach for restoration of the degraded land and biodiversity conservation and eco-environmental improvement (Cao, 2011). However, the establishment of vegetation on degraded land is constrained by insufficient moisture available in the root zone (Li *et al*., 2008), whereas low and irregular rainfall affects plant growth and survival too (Barron *et al*., 2003). When water resource is scarce, the need for water management skills and efficient use rises. In such areas, the water for growing vegetables and fruit trees can only be provided through SWC technologies like *in-situ* rainwater harvesting devices namely, infiltration pits, *half-moon* and soil level bund embankments.

Further, rainwater harvesting and storing supports flourishing plant growth and tree seedling survivals in many dry areas (Faroda *et al*., 2007). *In-situ* rainwater harvesting structures also have hydrological functions as it modifies water flows in the landscape mainly by enhancing water infiltration at plot scale (Wakindiki and Ben-Hur, 2002). These enhanced by reducing velocity of runoff, and the water is collected behind the structures.

These can be realized through well designed and improved soil water conservation and harvesting devices that may contribute in improving soil water storage capacity, essential soil nutrients mobility, and supports a higher number of tree seedlings survivals on the degraded land areas (Gowing *et al*., 1999).

Tree seedling plantations, using appropriate and well designed *in-situ* rainwater storing structures can play an important role in the tropical degraded environment restoration (Founoune *et al.,* 2002). In such cases, transplanting of nursery-raised seedlings may accelerate regeneration and afforestation of the degraded lands (Yirdaw and Luukkanen, 2003). Because, tree seedling is the primary means by which they are recruited into the forest canopy after disturbance (Smith and Ashton, 1993).

Successful tree seedling survival and growth depends on the soil condition and stored soil moisture available to ensure tree seedling survival into the next growing season (Warren *et al.,* 2005). Because, seedlings of some trees are sensitive to drought, and may be killed by even short dry spells (Engelbrecht *et al.,* 2007). Moisture availability and tree seedling survival have a strong relationship as the soil moisture supply is improved; high seedling survival rates can be obtained. However, the moisture availability in the root zone directly influenced by the SWC structures and natural slope gradient which in turn affects the growth, distribution and survival of transplanted tree seedlings (Ngigi, 2009).

Quantitative studies in a drought-prone district in Southern Ethiopia have shown that rainwater harvesting has improved the capacity of communities to deal with recurrent drought (Desta, 2010). Accordingly using SWC, farm households have started to introduce new vegetables and perennial crops, and increase their household income. The shapes and design of structures have a high contribution for the establishment of transplanted tree seedlings (Malik and Bhatt, 2016). Bunds, infiltration pits and negarims conserve runoff effectively where the profile can't hold water relatively well (Mati, 2005). Natural slope gradient also determines moisture as well as essential soil nutrients availability around planted tree seedling root zone and profiles (Grubb, 1977). The well designed SWC devices with respect to shape, size and slope position can enhance sufficient moistures and soil nutrients for the next growing season during the dry season (Fatondji, 2002).

In the dry and more degraded lands of Borana rangeland particularly Gerduba watershed, pastoralists, NGOs and GOs have been planting many tree seedlings species year after year but the survival of those seedlings are poor and variable as the area is mainly affected by moisture stress and soil fertility problems. The impact of SWC practices on the number of planted seedling survival per unit area at variable slope position has so far scarcely been investigated. Again, the area has not been given much research attention and are still lacking regarding the title. Therefore, the general objective of this study was to evaluate the performance of selected SWC structures (infiltration pits, *half-moon* and LSBE) in conserving moisture and improving tree seedling survival as well as physical soil quality under area enclosure rangeland management practices in this particular area as it is critical to understand tree seedlings establishment and growth.

1.2. Significance of the Study

The findings of the study will provide some information on impact of selected SWC measures which in turn will contribute information what type of SWC device at what slope position and how slope positions determine the types of soil and water conservation devices to the extension specialist and pastoralist. Moreover, the outcome could serve as input for future identification of the best appropriate IRWH system with respect to conserving and storing soil and moisture with appropriate slope position for tree seedling survival in the area, and provide data and show direction to assist future research.

1.3. Problem of the Statement

The driving forces contributing to rangeland degradation include, but are not limited to, deforestation, bush encroachment, livestock population pressure, consequent over-grazing. Vegetation removal is a common phenomenon in most of the hilly tract causing rangeland degradation (Arya *et al*., 2009). The removed vegetation replaced and/or encroached by unwanted bush. These bush encroachment can alter soil moisture and nutrients, microclimatic conditions and can suppress grass productivity (Roques, *et al*., 2001). But when put under protection from human and livestock interferences, these disturbed habitats may take longer time to recover naturally by colonizing plant and animal species (Abebe *et al*., 2006).

The process of degraded land rehabilitation can be accelerated through human intervention like afforestation (Sharma and Sunderraj, 2005) and conserving soil and water through rainwater harvesting system (Singh *et al*., 2013). This provides a basis for environmental improvement by way of improving seedling survival and growth. However, inadequate or insufficient availability of water and nutrients within the root zone affect transplanted seedling survival as well as natural vegetation regeneration (Gammoh, 2011) and there is need to supply additional moisture and soil nutrients. The Borana pastoralists in southern Ethiopia have planted a huge number of nursery raised seedlings in the different degraded parts of enclosure the catchments. But less and variable tree seedlings survival were seen from year to year across slope catchment. These problems may arise from less effectiveness of implemented SWC structures in conserving and storing soil nutrient and moisture due to unfit the shape and design of the devices with appropriate slope position of the catchments. Numerous studies have investigated the siting of SWC systems under current climatic conditions (Kadam *et al*., 2012), but most fail to evaluate the performance of these systems under different slope gradient as well as different shape and design of *in-situ* structures in conserving as well as storing the most essential soil nutrient and moisture in the root zone.

Generally, inappropriate SWC device selection with regard to slope position and degradation condition also affects the soil and water conserved and stored. Although many studies have been conducted in Borana rangeland on water resource shortage (Coppock, 1994), detail information on effect of (IRWH) methods for tree seedling establishment and growth in degraded rangeland are either lacking or non-existent. Besides, there are few studies with direct focus on water harvesting system and management categories in Borana zone. However, the extent to which different SWC structures influence soil moisture improvement, plant growth and rehabilitation process needs to be investigated under different topographical conditions particularly in the degraded enclosures part of Gerduba catchment.

1.4. Objectives

The specific objectives of this M.Sc thesis were:

- To identify the best performing SWC structure on tree seedling survival
- To compare the percent of seedling survival in selected SWC methods, and
- To determine the most important factors influencing SWC methods efficiencies in relation to moisture conserving and storing.

1.5. Research Questions

Thus, this study was geared to address the following research questions:

(i) Do seedling and SWC technologies have consistent relationship?

(ii) Are the tree seedling survivals across the different slope classes' viz. upper lands, middle lands and bottom similar?

(iii) Does the total (%) of tree seedlings survived in the each *in-situ* rainwater harvesting methods resemble each other?

(iv) Is there relationship between natural slope gradient, seedling survival and soil depth factors?

(v) What are the most influential factors affecting *in-situ* rainwater harvesting structures efficiencies?

2. LITERATURE REVIEW

2.1. Over View of Soil and Water Conservation Technologies

Soil and water conservation have different meanings and aims defined by different scholars. For instance, soil and water conservation means conserving and holding rainwater where it falls and prolonging the time for infiltration as easily available to plant root (Critchley *et al*., 1991). Other scholars conclude it as a method for inducing, collecting, storing and conserving direct rainfall or surface runoff for agriculture in arid and semi-arid regions (Boers and Ben-Asher, 1982). In order that, SWC system is a method that concentrates soil water in the rhizosphere for more efficient use by plants. The system aim at conserving the rainfall where it falls in the cropped area or pasture for more efficient use by plants (FAO, 2002). After infiltration has ceased, then follows the conservation of the stored soil water in the structures will be occurred. Therefore, soil and water conservation including *in-situ* rainwater harvesting is taken as moisture conservation device that provides the necessities of life for survival and growth of vegetation in general.

Soil and water conservation is basically a prevention of net runoff from a given cropped area by holding rain water and prolonging the time for infiltration. This system works better where the soil water holding capacity is large enough and the rainfall is equal or more than the crop water requirement, but moisture amount in the soil is restricted by the amount of infiltration and/or deep percolation (Critchley and Reij, 1989). SWC in arid and semi-arid regions is an old yet an effective way of establishing and subsequent growth of trees. It is a technique that was originally proposed in South Africa by Hensley *et al*. (2000) as an alternative to conventional crop production. It was designed to minimize unproductive losses of rainwater. The technique is an adaptation of the runoff strip method of conserving and storing soil and moisture used for tree seedling establishment and growth (Oweis *et al*., 2001).

A vast variety of traditional, as well as innovative SWC practices was exist around the world (Ngigi, 2003). Typical SWC structures are linear structures which are sometimes cultured, such as the Tera system in Sudan and terracing as practiced in East Africa (Van Dijk and Ahmed, 1993). Deep trench benefits to increase porosity reduce surface sealing of the soil and permits roots proliferation to exploit soil water and nutrients at deep horizons (Hudson, 1987). Semi-circular bunds are common in the semi-arid zones of Western Africa (Barry and Sonou, 2003). Infiltration pits also takes place in the form of Zai in Burkina Faso (Kabore and Reij, 2004), Tassa in Niger (Hassan, 1996), or the Chololo pits and Ngoro pits of the Matengo people in East Africa (Mati, 2005). The different systems differ mainly in the size of the pits.

A huge literature discusses on SWC throughout the world, but much interest in this was developed predominantly because of migration of more and more people to live and utilize the very scarce resources in dry areas (Mati, 2005). Many site-specific RWH structures have been designed to address the soil and water conservation issues and to increase plant growth and survivals (Gupta, 1995). Typically, *in-situ* rainwater harvesting systems do not cover a distance of more than 5-10 m from the point of water intake to the point of infiltration into the storage medium, mostly the soil. These include many such as retention ditches, vegetative buffer strips, soil bunds embankments, and other activities that reduce the loss of surface runoff water. They are primarily used to reduce soil erosion and to improve rainfall infiltration and storing moisture in the soil profile which is the most essential for tree seedling survival in moisture stress areas (Fraiture *et al*., 2007). Stored rainwater in the soil profile for plantation is sometimes referred to as "green water" and forms an important component for agricultural production. The SWC method such as infiltration pits, semi-circular bunds and level soil bund embankments are important devices to conserve and store moisture in the soil profile particularly in moisture stress areas (Zougmore´ *et al*., 2003).

Infiltration pit is a traditional practice developed by farmers in Burkina Faso that has been adapted in the wider Sudano-Sahelian zone for rehabilitating degraded fields that have been eroded and crusted over and thus with infiltration rates too low to sustain vegetation growth and survivals (Roose *et al.,* 1999). According to Amede, *et al.* (2014), Zai pits lead to water and nutrient concentrations within the root zone which is important vegetation growth and maintaining in Dryland areas.

2.2. Factors Determine SWC Structures Efficiency and Distribution

The design of a run-on facility depends on many factors, including catchment area, the volume of runoff expected, type of seedling transplanted, soil depth, and availability of labour (Hatibu *et al.*, 2001). However, the efficiency of conservation structure in conserving and storing rainwater for the dry season is determined by its depth and design (Hudson, 1987). There are essential factors that determine the distribution and efficiency of SWC structures over degraded parts of the catchments. For instance FAO (2002) as cited by Kahinda *et al.* (2008), lists the major key factors that determine the distribution of soil and water conservation structures includes climate (rainfall), hydrology (rainfall-runoff relationship and intermittent watercourses), topography (slope), soils (texture, structure and soil depth) and socio-economic activity (experience with *in-situ* rainwater harvesting, land tenure, water laws, accessibility and related costs).

Durga and Bhaumik (2003) identified land use, soil, slope, runoff potential, proximity, geology, and drainage as a criterion to identify suitable sites for *in-situ* RWH devices implementation. Kahinda *et al.* (2008), used physical (land use, rainfall, soil texture and soil depth), ecological (ecological importance and sensitivity category) and socio-economic factors to determine the distribution and efficiency of SWC devices. Soil depth and rainfall types are the major actors determining the distribution of SWC structures. Soil physical characteristics are therefore important factors.

There is a need to understand the complex interactions between ecology and hydrology involving SWC micro-catchments and their influences on the availability of soil water and the corresponding improvement in tree seedling survivals and plantation growth. Information on ecological and hydrological interaction may determine the resource use and its influence on plant growth and transplanted tree seedling survivals (Ludwig *et al*., 2005).

The biophysical requirements and limitations to design SWC structures correspond well with the conditions such as soil types and aridity (Critchley *et al*., 1991). For example, a typical Zai pit (30 cm diameter) density of 10,000 pits ha^{-1} in Northern Burkina Faso would represent a cropped area of about 7 %. This corresponds to 3 plants (typically three plants per pit), a value similar to 3.7 plants m^{-2} reported by Jones and Thornton (2003) for typical rain-fed smallholder maize production systems in the tropics. The capability of SWC structures in water storage, reliability as well as economic benefits also play an important role in determining the distribution and efficiency of the structures (Rahman *et al.*, 2012). Natural slope gradient is another most influential factor that determines the distribution and efficiency of SWC structures. Topographically low areas are ideal site for SWC structures implementation. On very steeper hills, SWC structures can be applied, though it is quite labored demanding (FAO, 2002).

2.3. Importance of Soil and Water Conservation Technologies

Soil and water conservation measures play a critical role in providing favorable condition by conserving, storing moisture and essential nutrients needed for tree seedling survival and natural vegetation regeneration (Malik and Bhatt, 2016). It can aid the transplanted seedling establishment in utilizing their low and erratic rainfall in order to rehabilitate the degraded lands (Kronen, 1994). Particularly in Dryland areas, poor tree seedling establishments are related to an insufficiency of soil moisture available within the root zone rather than to an insufficiency of rainfall (Boers and Ben-Asher, 1982). For reason that, as it conserves and stores rainwater within the root zone for dry season, tree seedlings never lose much more energy to absorb moister for metabolic activities in the plant tissue. On the other hand if there is a lack of moisture availability, the microhabitat couldn’t run their activity in a good manner (Liang and Seagle, 2002). These in turn affects essential soil nutrient availability in the root zone (Mati *et al.*, 2006). The soil microbial then also carries out of decomposing of different residual materials and release essential nutrients to transplanted seedlings.

Different soil and water strategies, such as infiltration pits, half-moon or level soil bund embankments implemented at the field level, act to shift a fraction of rainwater to productive purposes of collecting and storing water in the form of soil moisture within the plant root zone (Rockstrom *et al.*, 2002). This entails that water is made directly available to vegetation’s without a lot of energy requirements. They are not aimed at directly improving water use efficiency, but rather at reducing the variability in potential and actual vegetation growth and survival (Fox and Rockström, 2000).

It can also reduce seedling mortality due to soil degradation by water erosion. Among the most common SWC techniques, *in-situ* RWH is massively promoted by users in African countries (Stroosnijder, 2003) particularly in Borana rangeland where RWH practices already have a long tradition (Pandey *et al*., 2003). Studies conducted by Biamah and Nhlabathi (2003) have demonstrated *in-situ* RWH systems increasing crop yields by 30% to 50%. Moreover, SWC measures reduces the susceptibility of vegetation to the adverse effects of frequent dry spell events and has the ability to reduce inter-seasonal seedling survival variability associated with erratic climatic patterns(Barron *et al.,* 2003).

Fox and Rockstrom (2003) reported that SWC particularly *in-situ* conservation structures had a significant effect on grain yield, and by using this system in Burkina Faso they were able to increase the yield of sorghum from 715 kg ha^{-1} to 1,057 kg ha^{-1}. Micro-basin *in-situ* rainwater harvesting structures (e.g., half-moons, eyebrow basins, and trenches) have also been proven to be effective in improving tree seedling survival and growth in degraded lands. Experiences from northern Ethiopia have shown that these structures improved tree seedling survival and growth significantly compared to non-treated landscapes (Derib, *et al*., 2009). The seedlings grown in micro-basins were thicker, taller, and more productive than those grown in normal pits, suggesting a need to integrate tree planting with soil water management. Some of these interventions have been developed and used by communities in Africa for centuries, including, for example, by the Konso tribes in southern Ethiopia and by communities in Burkina Faso.

The primary limiting factors for tree seedling stabilization in semi-arid regions is the amount of moisture available within the root zone (Lal, 2001). Rainfall intensity in sub-Saharan Africa can often be greater than infiltration rate and the water holding capacity of the soil, which can trigger an excess of runoff. In sub-Saharan Africa where rainfall is low, unpredictable and also expected to decline due to climate change, the SWC structures can serve in storing additional moisture to satisfy water demands during dry spells for transplanted tree seedling survival (Ngigi, 2009). More than 78% of consumed water by vegetation comes directly from rainfall (De Fraiture and Wichelns, 2010). So, if there is no well-designed and suitable *in-situ* RWH structures, the total rainfall escape out of the rhizosphere.

Physical SWC measures have direct or indirect impact on tree seedling survival. According to Mekonen and Tesfahunegn (2011), as a result of physical SWC measures, the tree seedling survival rate rose to over 45%, and the vegetation composition and plant coverage density improved by more than 30%. Increasing seedling survival is encouraging and offers more hope to the people living in catchment than the absence of physical SWC measures.

Particularly, SWC structures play a crucial role in the establishment of tree species. As noted in Khosravi (2014), semi-circular bunds play a great role in increasing the number of plant species, soil microorganisms and nutrient content of the soil in the arid zone. It also encourages secondary succession in arid and semi-arid rangeland ecosystems (Delavari *et al.*, 2014). Appropriate structure and site selection, design, construction and spacing are important determinants of transplanted tree seedling survival. As reported in Wolancho (2015), under lack of appropriate structure selection, design and spacing, but appropriate tree species selection, poor seedling survival rate (<5%) was observed in micro-watersheds.

SWC techniques that aim at maximizing benefits of rainfalls where it falls are tremendously used and produce good results, especially in semi-arid zones (Li *et al.,* 2006). SWC system is more dominant and acceptable for users to rehabilitate the degraded lands. Ngigi (2003) attributed the dominant use of SWC to its simplicity, low cost and can be practiced in all land use systems. Improved SWC for rehabilitation has many potential benefits in the effort to reduce vulnerability and improve productivity (Awulachew *et al.,* 2005). As a result of SWC, Ethiopia’s agriculture sector has witnessed consistent growth since 2003.

2.4. Major Constraints of Seedlings Survival and Growth on Degraded Lands

2.4.1. Moisture and soil nutrient availability

The two main limitations of plantation survival and growth are, soil nutrients and moisture availability within the root zone and seedling's ability to access it (Grossnickle, 2005). Reforestation practices often dictate that the optimum time for tree planting is followed by the onset of the dry season (Waring and Franklin, 1979), resulting in progressively drying soil during seedling establishment. Reduced precipitation combined with plant transpiration commonly decrease soil moisture in the upper soil profile to below the requirement for seedlings to easily access (Warren et al., 2005). These reduced soil moisture conditions may be viewed as a significant barrier to artificial reforestation (Padilla and Pugnaire, 2007).

The seedling species performance could also plays an important role in establishment success because seedlings are generally less tolerant of stress and disturbance than adults (Titus and Moral, 1998). Though, tree species can differ in their response to resource availability during their critical phase of establishment which could influence forest dynamics (Sher *et al*., 2004). Microhabitat often determines seedling survival and growth, in disturbed and/or stressful sites (Liang and Seagle, 2002). Biotic microhabitats, i.e., patches formed by trees and shrubs, affect seedling establishment via decreased light and increased litter, soil moisture and nutrients (Rousset and Lepart, 1999).

Seedlings have the capacity to mitigate the post-planting drought by changing their root growth system. Nursery-raised seedlings are first out planted their root systems are confined to a planting hole and are limited in soil moisture uptake by their initial root size. To survive this initial drought, out planted seedlings must either close their stomata to conserve water or grow new roots into areas where soil moisture is more available (Burdett, 1990). Alternatively, a seedling stock type can be selected to pre-place root systems where they are able to access soil moisture more readily. In situations when roots are not placed in moist soils or new root growth is insufficient to mitigate moisture stress, negative growth and seedling establishment effects are observed (Burdett, 1990).

Knowing the seasonal moisture patterns and soil texture can offer insight on soil water capacity, soil water availability, and therefore, how quickly it can be depleted (Gardiner and Miller, 2004). To an establishing seedling, this means that root penetration to this depth can reduce drought effects. The availability of water deep in the soil profile has led to the anecdotal advocacy of planting longer (i.e. deeper) rooted seedlings to increase survival and growth. Only recently has scientific evidence supported this idea especially in rapidly drying soil profiles with competing for vegetation (Pinto *et al.*, 2012). According to Nyagumbo *et al.* (2009), study results show that the medium to heavy textured soils was considered more effective for water harvesting by farmers compared to the lighter textured soils.

A significant cause of low seedling survival and crop failure in rain-fed agriculture in the tropics is low and erratic rainfall. Specifically, rain-fed agriculture in semi-arid areas of Ethiopia is suffering from moisture stress which is a major limiting factor for the success of seedling survival (Leye, 2007). However, in many areas, crop and land management do not optimize water flow along the root zone. Thus, poor tree seedling survival is related to an insufficiency of soil moisture rather than to an insufficiency of rainfall.

Drought and moisture stress are the major problems in dry-land areas that most importantly affect the survival and growth of seedlings. As noted in Abraham (2014), among different factors affecting tree seedling survival rate, drought and moisture stress was perceived by 78.3% in the northern parts of Ethiopia. Most notably seedlings in dry-lands are highly limited by water availability and may have less survival in dry and moisture-stressed areas where desiccation is highly probable during the dry season. Soil and water conservation measures have a vital role in improving and maintaining soil fertility which in turn improves the WHC of the soil. Soil and water conservation structures act as sediment traps and therefore can enhance nutrient availability at the structures, as was shown for traditional Zai in Niger (Fatondji, 2002). These measures increase the amount of water soaking into the soil, reducing the speed and amount of water running off, and keeping sufficient vegetation to protect soil surface from detachment and binding the soil particles together (Gebretsadik, 2009). Soil and water conservation structures conserve soil and at the same time stores moisture for tree seedling survival.

Physical SWC measures particularly (IRWH) method have a crucial role in conserving moisture which is the main determinant for keeping tree seedling species alive and storing topsoil sediment subject to water erosion. The effect of SWC structures on biomass yield produced an increment of more than 25% for grain and 30% for biomass (including cover grass). This was as a consequence of the physical SWC measures that contributed to tree seedling survival by enhancing soil moisture and improving soil fertility with essential micro- and macro-nutrients (Mekonen and Tesfahunegn, 2011). By increasing soil water retention and supply, production can be improved significantly, and successful production can be possible even in areas of very limited production potential (Duveskog, 2003). Well-known and popular SWC techniques such as soil bund embankment and infiltration pits help to prevent runoff and increase soil water content.

Subsequent tree seedling survival followed similar patterns, resulting in even greater differences in cumulative success. The low survival of seedling species appears related to drought stress, as seedlings of forest species had lower predawn leaf water potential than savanna species (Hoffmann *et al*., 2004). The distribution of seedling survival is often associated with soil properties or moisture, with more seedlings survives on sites of the greater nutrient or water availability (Ruggiero *et al*., 2002). Often, soil properties across the savanna-forest boundary are not perfectly associated with vegetation type (Bowman, 2000). It is not always clear whether the soil properties determine the vegetation or whether the vegetation determines soil properties. However, tree cover can favor the accumulation of soil organic matter and nutrients (Mordelet *et al*., 1993) while the frequent burning typical of savanna may reduce these (Bowman, 2000).

The other low success of tree seedling is probably due to low shade tolerance and intolerant of waterlogged in which the soil poorly drained (Joly and Crawford, 1982). Seedlings of forest species exhibit greater water stress than seedlings of savanna species under similar conditions. It is widely asserted that deep roots permit savanna species to maintain favorable water status during dry periods by permitting access to moist soil layers.

In potted seedling studies, savanna species allocate more biomass to coarse roots than forest species (Hoffmann and Franco, 2003). If this corresponds to greater rooting depth, savanna species should exhibit greater seedling survival and reduced drought stress, as measured by predawn water potential. A previous study (Hoffmann, 2000) did not detect differences in survival between savanna and forest species in unburned conditions, but by using phylogenetically independent comparisons, we expected to increase statistical power to detect differences. Seedlings of savanna species are more able to survive fire than forest species (Hoffmann, 2000).

2.4.2. Natural slope gradient

The natural precondition required for SWC structures implementation includes many but the most determinant is the slope gradient is well known (Van der Marck, 1999). Because it affects tree seedling establishment patterns by changing niches moisture, temperature, and wind intensity (Srutek and Leps, 1994). Tree seedling survival and growth is significantly decreased from lower slope gradient to upper slope gradient (Yu *et al*., 2013). For reason that SWC device and natural slope gradient increases will enhance water and soil nutrients availability within the transplanted tree seedling root zone (Ngigi, 2009). These resulted due to increased soil and water heterogeneity exists across slope gradient as erosion is high on the higher elevation and low on lower elevations which in turn determine moisture and essential soil nutrients for tree seedling survivals.

Spatial heterogeneity in micro-environments may provide unique regeneration niches for tree seedling survivals and may promote forest diversity (Beckage and Clark, 2003). Altitudinal variability in environmental conditions that affect the survival and growth of tree seedlings may act as the filter that differentially affects tree species (Harper, 1977). Environments favoring seedlings of a particular species might function as regeneration niches that promote species existence (Huston, 1994). However, the potential for spatial heterogeneity in micro-environments to maintain forest diversity depends on the interactions of different sources of heterogeneity across spatial scales. Moisture and soil nutrients availabilities are the potential sources of spatial heterogeneity in micro-environment to maintain tree seedling survival diversity, all of which may limit seedling survival and growth (Pacala *et al*., 1994).

Whittaker (1956) described the regional vegetation in relation to elevation and moisture, including mixed oak forest, which is the most widespread forest type in the southern Appalachians. Tree seedlings growth and survivorship highly responses to variable exist across natural physical future gradients as soil resource availability in the area is generally associated with features of the landscape which differ in soil texture (Host *et al*. 1988), and water availability (Zak *et al*., 1989). Other scholars indicates the reason as, slope gradient is a very important factor affecting soil erosion intensity (Fox and Bryan, 1999).

Slope site with an upslope area is a niche that could contribute to the translocations of essential soil nutrient and moisture while plateau sites had no upslope area so, the water standing will exist (Daws *et al*., 2002). Variation in the topographic position is a further source of heterogeneity in tropical forests and some shade tolerant species have their adult distribution significantly biased towards certain topographic positions (Segura *et al*., 2003). Factors related to topographic position that potentially affect seedling establishment include soil water availability (Daws *et al*., 2002) and pH and CEC (Silver *et al*., 1994).

In contrast, tree densities gradually decrease with increasing elevation on Mount Koma, northern Japan (Kondo and Tsuyuzaki, 1999), indicating that tree survival gradually changes along the slope gradient and are an intrinsic part of biological invasions in mountainous areas. This is because, in sloping areas, the losses of top fertile soil and moisture in the form of erosion are expected to be higher and yields should vary more throughout the field (Earnshaw and Orr, 2013). Accordingly, report concluded that the soil moisture has a positive correlation with transect point; as one proceeds down the slope (with the higher numbered transect points at the bottom of the slope), one expects that soil moisture should also rise which may induce differences in soil moisture along the slope gradient. Due to slope gradient soil nutrient availability, soil texture, and moisture were probably contributing to less tree seedling survival and vegetation growth at Upslope.

Various authors have suggested that tree seedling establishment and survivals related to topographic position reflect species-specific plant responses to water potential gradients associated with topographic variation (Gibbons and Newbery, 2003). According to the study by Hubbell, (1998), slopes of the 50 ha forest dynamics plot on Barro Colorado Island (BCI) have 30–50% more species than adjacent plateau sites suggested this results from the presence of moisture-demanding species and drought-tolerant species on slopes in which the only drought-tolerant species occur on plateau sites.

Tree seedling survivals of transplanted seedlings vary, to a large degree by topography, which is a strong proxy for environmental conditions (Daws *et al*., 2002). In southern New England forests, topography creates broad gradients in resource availability, particularly soil nutrient and moisture, which likely influence growth and survival of different tree species. More tree seedling survivals in valleys, driven by high moisture and soil nutrient availability (Ashton *et al*., 1998).

Therefore, one possible explanation for the higher species richness on slopes is that seedling survival, particularly during the first dry-season post-emergence, will be greater on slopes since they maintain a higher dry-season soil water potential (Daws *et al*., 2002). This may be most apparent for small-seeded species since their small size, and related slow root growth rates (Daws *et al*., 2003) will reduce survival during dry-spells. This is also likely to be reflected in selection for emergence early in the wet-season to enable seedlings to reach as large a size as possible prior to the dry-season, since dry-season survival may be correlated with seedling size (Poorter and HayashidaOliver, 2000).

But some scholars disagree on the idea of topographic variation influences tree seedling survival and vegetation growth. Most recent models to predict soil erosion from small catchments require data on the spatial variability of soil moisture availability. Likewise, predicting soil moisture availability only from topographic parameters is hazardous because conflicting relations between slope gradient and moisture availability have been reported. Some authors observed no impact of natural slope gradient upon soil moisture availability which is essential for tee seedling survival and vegetation growths (Mah *et al*., 1992). Although many experiments more commonly showed a decrease in soil moisture availability with increasing slope angle due to a decrease in overland flow depth and surface storage observed decreasing infiltration rates until a slope threshold and then a steady infiltration rate independent from slope (Chaplot and Le Bissonnais, 2000). More surprising are the studies which showed increasing infiltration with slope gradient (Bradford and Huang, 1992).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Area coverage, location and topography

The study was carried out in Gerduba watershed which is found in Yabello district of Borana zone in the southern part of Oromia National Regional State. Yabello is the capital town for the Borana zone and is situated south to Addis Ababa at a distance of 570km. The Borana lowland is usually known as the southern rangelands. The rangeland lies west of Genale River and east of the Segan River. The southern limit of the rangeland goes up to the Ethio-Somali and Ethio-Kenyan borders, its northern limit is bounded by the cultivated lands, and Jemjem high forests (Alemayehu, 1998). The Gerduba catchment is located in the southern parts of Ethiopian lowlands (Fig. 1) and they cover a total land of 3220ha (WLRC and CDE, 2013). It extends from 4˚ to 5˚ latitude and 38˚ to 40˚ longitude and the maximum and minimum altitudes of the watershed are 1970 and 1550m above sea level, respectively. Accordingly, the relief (variation of elevation between the highest and lowest point) is 420 meter above sea level (Coppock, 1994). The terrain of the central Borana Plateau includes a central mountain range, scattered volcanic cones and craters and gently undulating and flat plains (Coppock, 1994). The Gerduba watershed is divided approximately into two dissections (aspects): the western and eastern aspects, by a river called *Kaa-Hara-Konitu* that stretches north-south through the watershed.

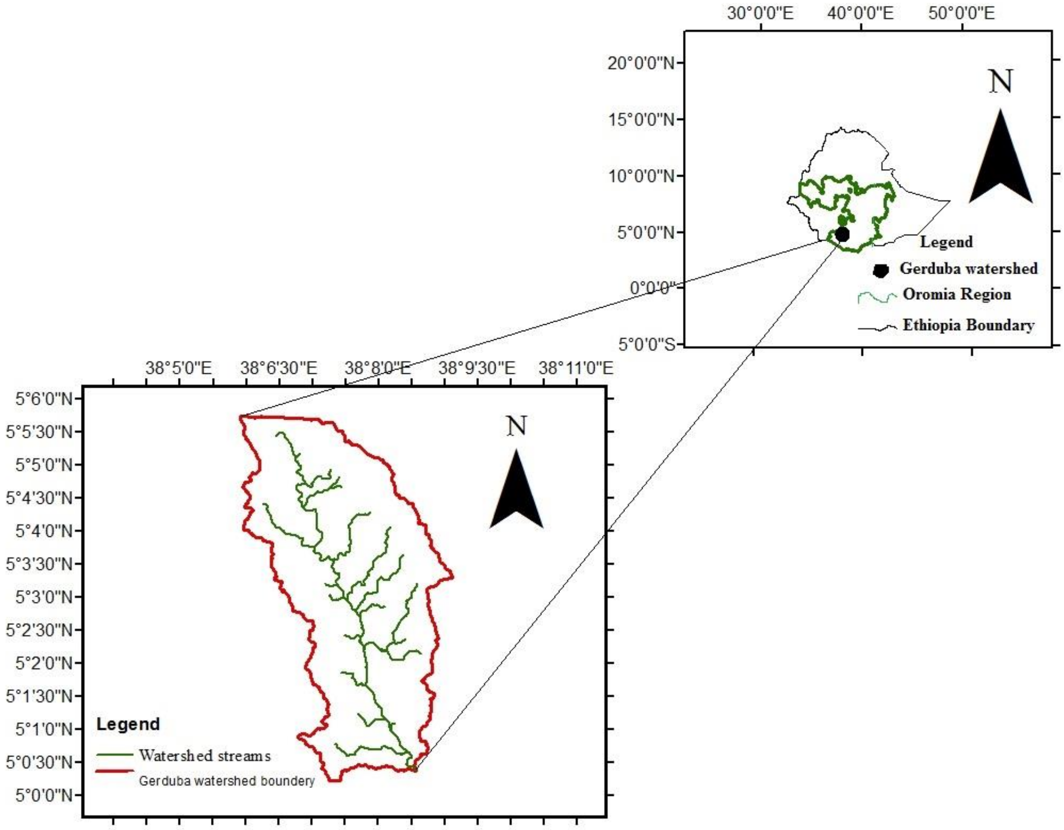


Figure 1: Map of the study area, showing the specific site in Yabello district

3.1.2. Geology and soil

The geology of the study area (Yabello district) is dominated by 40% quaternary deposits, 38% basement complex formations, and 20 % volcanic (Tefera *et al*., 2007). However, the main soils of the region comprise 53% red sandy loam soil, 30% black clay and volcanic light colored silty clay and 17% silt and Vertisols (Coppock, 1994). According to Angassa and Baars (2000), soils of the study sites are shallow red sandy loam in the uplands and Vertisols in the bottomlands. The area is notable for its red soils, which have little organic matter. Soil develops over time in response to interactions of parent material, weathering and accumulation of organic matter (Coppock, 1994). Overall, rangeland soils of East Africa are regarded as having low fertility. This is principally attributed to the very old age of common parent materials (Pratt, 1987).

3.1.3. Water resources potential of the watershed

Water and pasture are the two most important resources in the Borana dry land pastoral system. Borana society calls these two resources as *marra-bisaan*, which means grass and water, respectively. They also say *marra bisaaniin dheedan*, which means the utilization of pasture depends on the availabilities of water. This indicates that the two are inseparable but complementary resources.

In other words, pasture land cannot be used if water is not available in the area. Water is the most important resource for the Borana pastoralist community. Its availability, distribution and ownership determine not only pastoralists' mobility but also the sustainability of their livelihood. It determines largely the way the pastures are utilized, the time when pastoralists migrate, the number of livestock the community can have, etc. The water resource management and utilization arrangement shapes the culture of the Borana pastoral community. In Borana dry land, annual rainfall is very limited due to a couple of reasons: the amount of water stored in the soil surface is small, and the stored water is quickly lost due to evaporation. Shortage of water was a recurrent problem seriously affecting the entire Gerduba community before water resource development intervention was undertaken.

3.1.4. Vegetation

The vegetation comprised in Borana is mainly a mixed savanna which is dominated by perennial grasses (*Cenchrus*, *Pennisetum*, and *Chrysopogon spp.*) and woody plants (Desta and Coppock, 2002). The major herbaceous species found in Gerduba watershed include, but are not limited to, *Chrysopogon plumulosus, Aristida adscensionis, Harpachne schimperi, Bothriochloa insculpta, Cynodon dactylon, Eleusine indica, Digitaria milanjiana, Commelina benghalensis, Indigofera spinosa, Sida ovata a*nd *Cenchrus cilaris.* Some species of woody vegetation that are dominant in the watershed study area are *Vernonia phillipsiae, Acacia brevispica, Grewia tembensis, Balanites aegyptiaca, Dichrostachys cinerea, Acacia tortilis* and *Acacia seyal* (WLRC and CDE, 2013).

3.1.5. Climate

The climate is arid and semi-arid with relatively cool annual average temperatures (19-24°C) and a mean annual rainfall ranging from 300 mm in the lowland up to 1000 mm in the higher elevations. It is worth pointing out that the annual precipitation distribution is bimodal, with 60% falling from April to May and 30% from October to November. The rangelands of southern Ethiopia are arid and semi-arid with pockets of sub-humid zones (Coppock, 1994).

Table 1: Mean monthly temperatures at YPDARC meteorological station (˚C).

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MMMxT	28.4	29.1	28.2	26.0	24.9	24.7	24.0	25.0	26.3	25.6	25.9	26.8
MMMiT	12.7	14.2	15.7	16.2	15.5	14.7	14.1	14.2	14.9	15.6	14.4	13.1
MMAT	20.5	21.5	21.6	21.0	20.1	19.2	19.1	20.0	20.3	20.4	20.1	19.8

Note: MMMxT-Mean monthly maximum temperature; MMMiT- Mean monthly minimum temperature; MMAT-mean monthly air temperature

Rainfall is bimodal with the long (*gannaa*) rains expected between March and May and the short rains (*hagaya*) in October and November (Upton, 1986). The short rains of *hagaya* are followed by a long dry season (*boona hagaya*). Erratic rainfall results in greater variability in forage supply; range production is greater during above-average years compared to the below-average years, while drought years have almost zero production (Cossins and Upton, 1988). To survive with inconsistent range productions, the Borana pastoralists combined mobility and sedentary livestock management. Water from the deep hand dug well complexes is an important resource for regulating stocking rates (Helland, 1980).

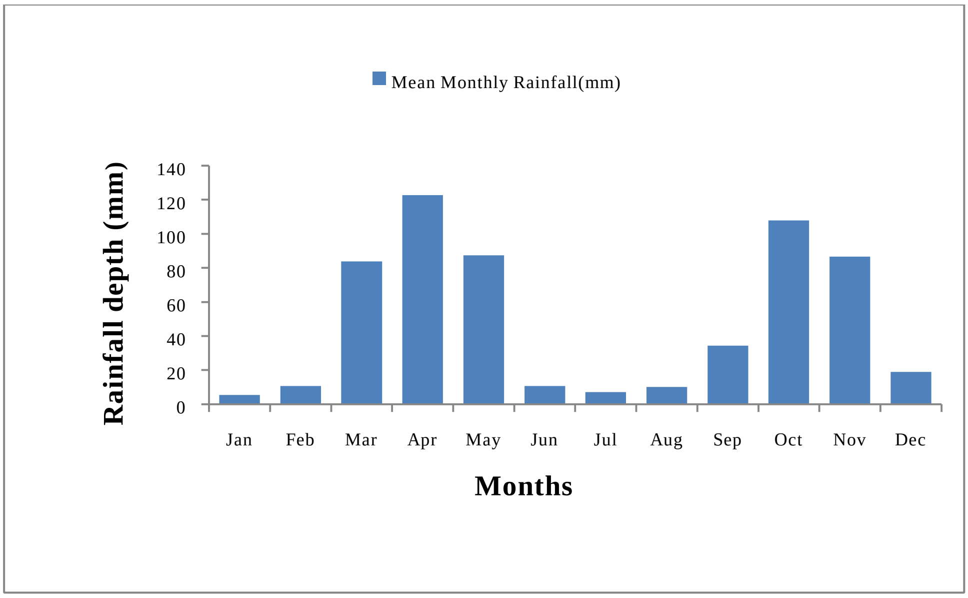


Figure 2: Mean monthly rainfall for Yabello district from 1998 to 2016

3.2. Socio-economic Characteristics

3.2.1. Human population and settlement pattern

The total size of the population in the watershed is presented in Table 2. In the watershed, the average family size reaches about 5 people per HH, where the proportion of female population exceeds that of male (WLRC and CDE, 2013).

Table 2: Total population of Gerduba watershed (Source: WLRC and CDE, 2013).

S/N	Category	Population		Total
		Male	Female	
1	Total population	1587	1634	3221
2	Household heads	317	327	644

In terms of age composition (Fig .3), most of the family members are youthful, in which the age groups under 15 years comprise 56.9%. The age groups ranging between 15-35 years constitute 26.4%, while 31.8% of the population is between the ages of 15 to 45 years i.e., the working age population. The higher number of young people in the population means there is no labor shortage; on the contrary, rather due to absence of alternative livelihood options, there is underemployment of people in the watershed.

Moreover, a large number of young people (<15 years of age) shows high dependency and create a socio-economic burden.

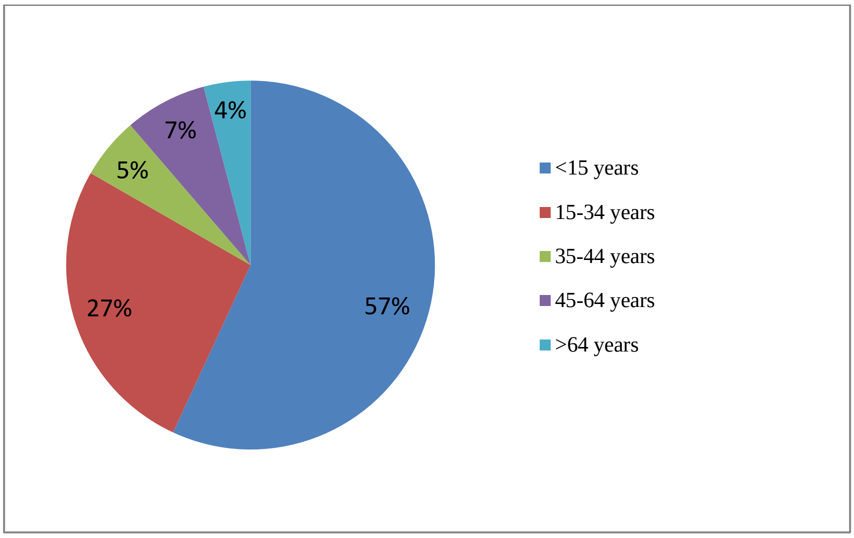


Figure 3: Age categories of Gerduba community (Source: WLRC and CDE, 2013).

3.2.2. Livestock population

The Borana pastoralists traditionally depend mainly on cattle, but also on goat and sheep and nowadays though few on camel for household food security and a few donkeys and camels for transport. The local *Zebu* known as the Borana cattle breed is bred and kept in Borana rangeland and plays a major role in the traditional Borana pastoralist production and livelihood system (BLPDP, 2004). This breed has good milk and meat production potential besides adapting adverse environmental condition under arid and semi-arid environmental conditions, which is developed through time and selection. Cattle take the largest number being 204370. Goat, sheep and camel were 98781, 39073 and 23852, respectively, in 2009 Yabello District Pastoral Development office (YDPDO).

3.2.3. Grazing land category

Following the type of herd and their mobility, grazing lands are categorized into two groups. Areas having sufficient forage and water resources throughout the year that can accommodate a particular cattle stock are considered as dry season grazing areas.

Conversely, those areas with limited resources that could last only until the end of the wet season are considered as wet season grazing areas.

The potential of an area to be a dry season grazing area is evaluated by the availability of permanent water and sufficient forage sources. Therefore, referring to the water resources map of the watershed, it is possible to identify the likely and potential dry season grazing areas of the watershed. In Gerduba watershed, all water facilities found within the watershed don't have water available during the dry season. As a result, the watershed couldn't fulfill the criteria to be a dry season grazing area, especially for the big herds that need huge forage and water resources.

Hence, there is no, if any, area within and around Gerduba that could be taken as a long dry season grazing area for *loona fooraa* herd group. As a result, the Gerduba community travels with their livestock (*loona fooraa*) to places very far away for an extended period during the dry season. Gerduba watershed is only used for wet season grazing or for the short dry season (i.e., June to September) for *loona warraa* livestock herd types. Hence, the resources available in the watershed are used only by those herds which do not travel long distances, including lactating caws, calves, and weak and old cattle, short traveling camels, sheep and goats.

3.2.4. Degradation story of Gerduba watershed

The degradation status of Gerduba watershed is indeed very severe. Bush encroachment is one of the study area problems which pastoralist consider equivalent to soil erosion that makes the land unproductive. It is therefore possible that unpalatable vegetation cover and weed infestation are directly related to pastureland degradation which may result in change in species composition of original species (Fynn and O'Connor, 2000).

Short, intense and erratic nature of the rainfall and the area's undulating topography make Gerduba watershed in particular and Yabello *woreda* in general more vulnerable to soil erosion. The landscape of Yabello town surroundings, where Gerduba watershed is located, has a relatively rugged terrain as compared to the other areas of the Borana zone (WLRC and CDE, 2013). As a result, soil erosion gradually became prominent and adversely damaged the rangeland ecology. Apart from the rills and gullies that significantly reduce forage quantity and quality, there are termite mounds locally known as *kuyisa*. The more the land is degraded the more are the numbers of termite mounds (*kuyisa*).

3.3. Site Selection and Field Layout

The different *in-situ* rainwater harvesting structures practices with planted seedling in enclosure catchment area, at different slope positions are sought for this study were: infiltration pits, level soil bund embankments and half-moon or semi-circular bunds. Area enclosure was selected due to the presence of the three types of *in-situ* rainwater harvesting structures with planted tree seedling to control the variations or extraneous from human or livestock's on tree seedling survival as well as on structures or to accommodate the similar data of survived seedlings.

Prior to the field layout and sampling techniques, the reconnaissance survey and discussion was made with experts who have a deep knowledge of the site starting from its initial management practices to its present situation. In order to establish similar topographical position and permanent plots, the slope position was classified in to three slope classes. The three catchment parts identified for this study were bottom part (0-5% slope), the middle part (6-10%) and the upper (shoulder) part (>10%). Because, soil moisture and soil nutrient availabilities are mostly influenced by natural slope gradient. These classifications were done based on recommended *in-situ* rainwater harvesting suitability. The way of classification is similar with that of slope position classification adopted by (Engda, 2009; Alem *et al.,* 2016). Then, 10m x 10m size quadrants were used to sample the transplanted seedling for the survival counting. The area of interest was clearly identified in such a way that detail observation was made around the area to be sampled to assure that the sample plots do not all fall in the area with the densest or least dense seedling area.

3.4. Experimental Sampling and Study

The Gerduba catchment is one of the largest protected areas from human and livestock entrances extending to 3220ha. The present study was carried out at three different topography positions of classified in to similar classes in the protected parts of the catchment. The study components of this thesis were the tree seedling survivals in different *in-situ* rainwater harvesting methods (infiltration pits which was prepared with depth of 0.5 m, width=0.5 m, space across the slope=0.5 m, along the slope in staggered manner=2 m apart, *half-moon* (semicircular micro basin) which was prepared with diameter of 1.5 m, space across the slope=0.5m, ridge around periphery=0.3m high and 0.6 m wide, down the slope in staggered manner=2 m apart and pits which was prepared with diameter=0.4 m, depth=0.4m and , soil level bund embankments which was constructed with the of depth=0.5m, length=38m and 1.1m wide) and selected soil physical properties. The classified topographic position in to upper parts, middle parts and bottom area were used in the whole studies. The details of the methodologies and field plot layout are here under (Fig 4).

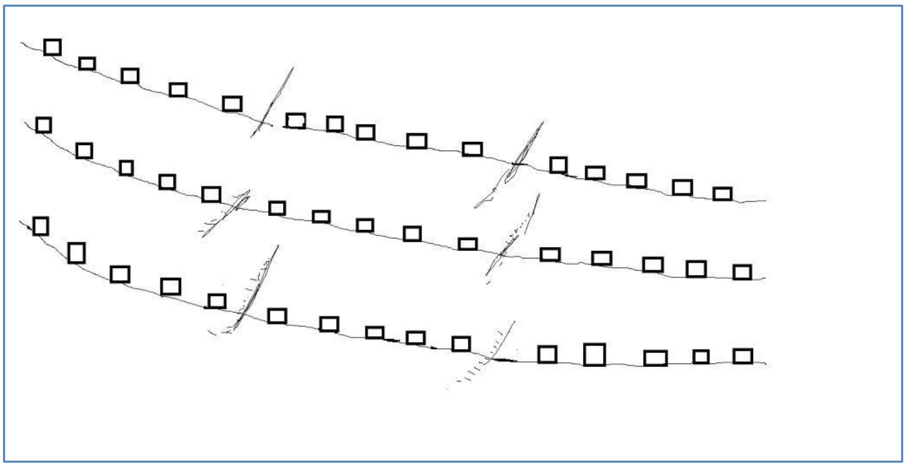


Figure 4: Field plot layout of the experimental site

Key: Transects at 10x10m were allotted for quadrant tree seedling sampling quadrants were sampled at the three within each plot or slope classes with five respective replications.

NB: Plots or slope classes orientation (the 30m side of the plot always runs from South to North or vice versa and the 40m side of the plot always runs from East to West or vice versa to make all plots arrangement uniform).

3.4.1. Transplanted tree seedling sampling techniques

Stratified, random samplings of 10m x 10m size quadrants from each slope classes were taken repeatedly after transact walk thoroughly the slope classes. Because, a single quadrant cannot be expected to sample a survived seedling represents the whole seedling population adequately. So, once collected, the sample data from all quadrants are added together and considered to constitute an adequate sample of tree seedling survived in each slope classes of constructed *in-situ* rainwater harvesting systems. At each quadrant, the total numbers of survived tree seedlings transplanted were thoroughly counted. Saplings less than 2cm of diameter at breast height were excluded because most likely they would not survive. In each slope classes, a total of forty five (45) quadrats of 10 m x 10 m size were used to count tree seedling survival in the each in-situ rainwater harvesting structures of area enclosure parts (Fig 4). Fifteen quadrant samples that were collected from each slope class (plots) were bulked together to represent a block. The numbers of quadrants were determined based on number of counted tree seedling survived in the quadrants variation.

3.4.2. Sampling of soil physical parameters

Soil texture was determined by using hydrometer method (Day, 1965), while bulk density was determined by core method (Blake, 1965). A known volume of soil coring ring with a radius of 2.983cm was used for determination of soil bulk density for the three depth levels i.e. 0-10 cm, 11-20 cm and 21-30 cm. Undisturbed or soil coring was performed when the soil has not lost most of its natural condition such as moisture content, compactness and etc. in order to prevent any loss of soil from the coring ring while revolving by high speed down into the ground. When the intended depths were attained, the soil core was pulled out of the soil with care and then struck by a rubber hammer that does not harm the coring ring to release the soil contained in the soil core into a bucket. Soil core sampling was done from five points per plot and then the soil samples from the five points were composited to represent a plot according to their respective depths. The composited soil samples by their depths were then oven dried at 105^{o}C for 24 hours. Bulk density was finally calculated as the ratio of the mass of oven dried soil sample to its core volume.

3.5. Methods of Data Analysis

The counted Survived seedling was calculated as the proportion of surviving trees to total number of trees of the same species planted in the enclosure parts of different *in-situ* rainwater harvesting structures. Plot means for three variables were calculated. Treatment comparisons of means were made at 5% level of significances using Least Significant Difference (LSD) test (Steel and Torrie, 1980), independently and dependently. Independent analyses were executed for tree survival in different *in-situ* rainwater harvesting and then combined analysis was done to observe if there is significant variation between slope classes in relation to planting techniques. The tree seedling survival and soil attributes data were analyzed using the statistical analysis system with version 9.1 (SAS, 2002). The analysis of variance (ANOVA) was attributed to all data that were generated from tree seedling survival and Least Significant Difference (LSD) test with $p < 0.05$ was employed for mean comparison. The data that was generated from soil attributes were analyzed as 3x3 factorial experiments with RCBD using SAS (SAS, 2002); the three *in-situ* rainwater harvesting method practices and three levels of slope classes were used as the two factors with both three levels, respectively. The model included the effect of *in-situ* rainwater harvesting methods, slope classes and their interactions. Whenever significance differences was detected through ANOVA with $p<0.05$, Tukey's studentized test was employed for further mean comparison.

4. RESULTS AND DISCUSSION

4.1. Tree Seedling Survivals in and/or Around SWC Technology practices

The impacts of SWC technologies particularly, the selected *in-situ* rainwater harvesting devices namely, infiltration pits, semi-circular bunds or *half-moon* and level soil bund embankments on moisture availability across the slope classes were evaluated indirectly using some indicators. Grass regeneration and maintaining around *in-situ* rainwater harvesting devices as well as transplanted tree seedlings stay alive are excellent indicators of moisture availability (Fig. 5). The status of rangeland degradation could be estimated from regenerations, maintaining and seedling survivals. This finding supports the results of (Abraham, 2014), who reported that the effects of moisture stress account for more than 87.9% in the death of tree seedlings. In similar ways, the moisture stress commonly limits growth, survival and distribution of tree seedlings (Warren *et al.*, 2005). These reduced soil moisture conditions may be viewed as a significant barrier to artificial reforestation (Padilla and Pugnaire, 2007).

Figure 5 : Tree seedling survived in (a) pits, and (b) level soil bund embankments

The analysis of variance revealed that the interaction of tree seedling survival with planting methods was found to be insignificant (P>0.05) particularly in *half-moon* and infiltration pits implemented in enclosure parts of the study area. Similar result was reported in Desalegn *et al.* (2016), explicitly, the non-significant effects of moisture conservation structures on seedling survival. The main effect of moisture conservation structures on conserving and storing moisture was not significant except level soil bund embankment (Table 3). The finding confirmed the previous finding of Malik and Bhatt, (2016) who concluded that the amount of moisture conserved in soil profile mostly influenced by type and design of *in-situ* rainwater harvesting devices. Because, in level soil bund embankment, tree seedling raised in the nursery site transplanted to the embankment of structures i.e. on the dig out soils. In similar way, Boers and Ben-Asher, (1982) suggested that poor tree seedling establishments are related to an insufficiency of soil moisture available within root zone rather than to an insufficiency of rainfall. In order that, the moisture is conserved in the structure which is not nearby to the transplanted seedling roots, as a result needs more energy to absorb but weak and short rooting system. The finding was in line with the previous stated from some scholars who indicated that the major limitations of plantation survival are soil nutrients and moisture availability within the root zone and a planted seedling's ability to access it (Grossnickle, 2005). On the other hand, level soil bund embankment covers a large open space exposed to sunlight for more evaporation than infiltration pits and half-moon *in-situ* rainwater harvesting structures. Moreover, reduced precipitation combined with evaporation commonly decrease soil moisture in the upper soil profile to below the requirement for seedlings to easily access (Warren *et al*., 2005).

With respect to planting methods, species planted .i.e. *Grevillea robusta* in infiltration pits and *half-moon* is relatively higher seedling survived compared with in level soil bund embankment respectively (Fig. 6). This indicates that infiltration pit and *half-moons* are more effective of conserving and storing moisture which is essential for seedling survival and growth. This is in accord with the previous findings of Malik and Bhatt, (2016) that as shape and design of moisture conservation have contribution for the establishment of planted tree seedlings.

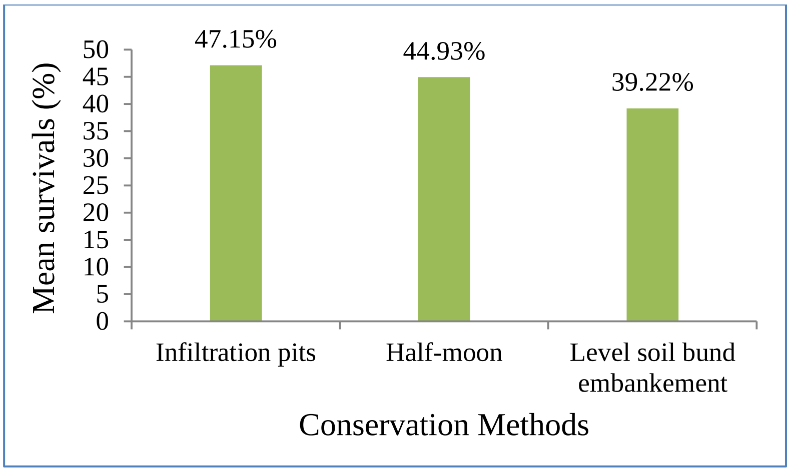


Figure 6: Total mean seedling survival (%) comparison between selected *in-situ* rainwater harvesting structures

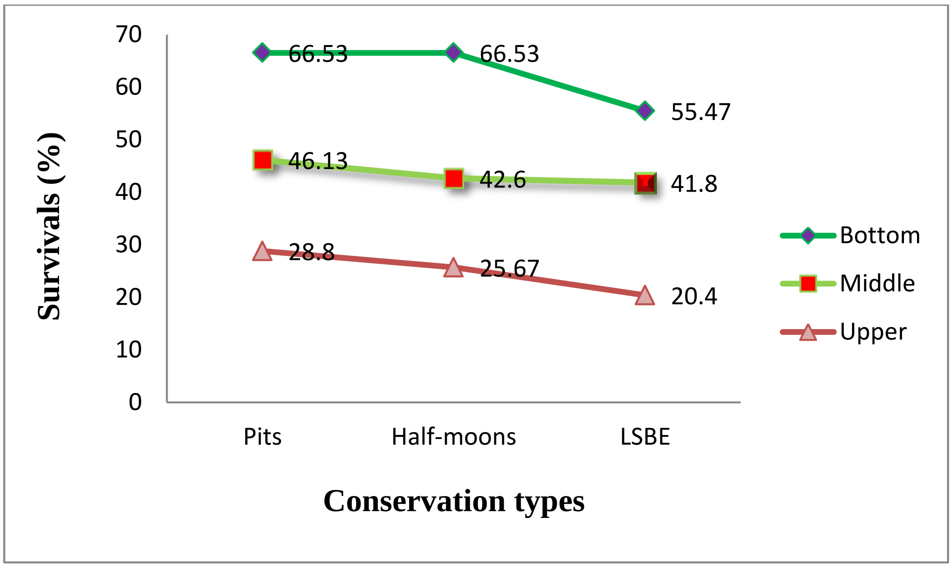
Infiltration pits and *half-moon* showed good performance at bottom parts while; level soil bund embankments is relatively least perform at bottom parts (Table 3). The finding strengthens the report that tree seedling survival and establishment is significantly decreased from lower slope gradient to upper slope gradient (Yu *et al*., 2013). The previous study stated indicated that the efficiency of *in-situ* rainwater harvesting (RWH) structure in conserving and storing rainwater for the dry season is determined by its depth, design and slope position (Hatibu *et al*., 2001). Infiltration pits attain significantly higher performance at both 0-5% and at >10% slope of slope position where the soil is relatively better in moisture status and infiltration capacity as compared to half-moon and level soil bund embankments respectively (Fig. 7). Although the analysis of variance reveal that there was no significant difference in survival (%) of tree seedlings with respect to different planting methods during the assessment periods, the mean survival of seedlings planted in half-moon (41.80%), infiltration pit (46.13%) and level soil bund embankment (42.60%) at 6-10% slope classes (Table 3). But significant difference in survival % of *Grevillea robusta* species at >10% slope classes, the mean survival of seedlings planted in infiltration pit (28.80%), half-moon (25.67%) and level soil bund embankment (20.40%).

Table 3: Mean survival (%) of the tree seedling in different planting methods at three slope classes at enclosure parts of Gerduba watershed

Planting methods	**Mean survival (%) of tree seedlings at different slope classes**		
	Slope class (0-5)	Slope class (6-10)	Slope class (>10)
Infiltration pits	66.53[a]	46.13[a]	28.80[a]
Half-moon	66.53[a]	42.60[ab]	25.67[a]
Level soil bund embankment	55.47[b]	41.80[b]	20.40[b]
CV (%)	12.39	12.40	22.86
P- value	0.0003	0.0760	0.0009

Means in columns with the same letters are not significantly different

At bottom parts of the catchments, 66.53%, 66.53% and 55.47% of tree seedlings survived in infiltration pits, half-moon and level soil bund embankments, respectively (Fig 7). In contrast, 28.80%, 25.67%, and 20.40% tree seedlings survived at upper parts in infiltration pits, half-moon and soil level bund embankments, respectively. This explains that almost all *in-situ* rainwater harvesting structures play a crucial role at bottom or flat land rather than middle and upper parts of the catchment. This finding was in congruent with previous results of Daws *et al*.,(2002) that slope site with an upslope area is a niche that could contribute to the translocations of essential soil nutrient and moisture while plateau sites had no upslope area so, the water standing which very important for tree seedling survival.



[1]

Figure 7: Mean seedling survival (%) comparison in selected *in-situ* structures at different slope classes

[1] For the abbreviation of the third conservation type is as follows-LSBE: Level soil bund embankment

During the assessment of quadrant sampling the number of mean tree seedling survival in infiltration pits structures increases from lower to upper namely, in quadrant 8 and 15 within slope class III (Appendix Table 1). For reason that, there was stoniness in planting structures and additionally might be from inappropriate seedling plantation due to carelessness during site selection and root seedling pruning. This is in agreement with Wolancho (2015), who pointed out that under lack of appropriate structure site selection, design and spacing, but appropriate tree species selection, resulted in poor seedling survival rate (<5%) was observed in micro-watersheds. Transplanted adult seedling roots also may affect for not survival of seedlings. Burdett (1990) also reported that in situations when roots are not placed in moist soils or new root growth is insufficient to mitigate moisture stress, negative growth and seedling establishment effects are observed.

Tree seedlings survived in bottom parts where the soil is relatively better in moisture status and infiltration as compared to upper slope classes. This finding on the other hand supports the previous results of Gebretsadik (2009) who reported that most tree species planted to rehabilitate degraded lands are restricted to gentler slopes, and survival increased in planting pits compared to a significant decline on steep slopes. Because, the infiltration pits conserve and store moisture at <10% slope efficiently due to that no variation in moisture availability across the slope. However, *half-moon* is well performing in conserving moisture at bottom parts than middle and upper parts of the catchment respectively (appendix Table 2). The mean seedling survival % in level soil bund embankment was highly significant difference at ($p< 0.01$) in bottom part with that of upper part (Appendix Table 3). Even if, the conserved and stored moisture and nutrients are far from transplanted seedling roots it stay prolong for infiltration which might be easily accessible for seedling roots at bottom parts. Similarly moisture and soil nutrients availabilities are the potential sources of spatial heterogeneity in micro-environment to maintain tree seedling survival (Pacala *et al*., 1994).

The seedlings that survived in semi-circular bunds at different parts of the catchment show highly significant differences at $p<0.05$ between the bottom and upper parts and significant differences at $p< 0.05$ between middle and upper parts of the catchment (Appendix Table 2). Because, the direct rainwater harvested from the whole corners collected at the center bottom embankment parts of the structures. Though, slope position suitability is the most determinant for more efficient moisture conserving in semi-circular bunds with planted seedlings. Due to slope gradient, the moisture gets very close to embankment as a result, high probability of absorption and lateral water movement of moisture to unusable by seedling. Similar evidence from Burkina Faso (Zougmore *et al*., 2003) suggested that the soil moisture and nutrients increases significantly below semi-circular bunds. Moreover, successful tree seedling establishment and growth in the catchment depends on the stored soil moisture in the structures to ensure survival of tree seedlings into the next growing session.

4.2. Important Factors Determine SWC Efficiency

4.2.1. Physical soil characteristics in area enclosure

The most important soil physical properties in relation to study effects *in-situ* rainwater harvesting methods at each slope classes are discussed separately in the following sections.

4.2.1.1. Soil texture

Analyzed soil texture data across depths and slope classes of area closure with selected *in-situ* rainwater harvesting devices were indicated in Table 4. Different plant seedlings have adaptations to and preferences for specific soil types and the distribution of tree seedling survival is often associated with soil properties or moisture with more seedlings survives on sites of the greater nutrient or water availability (Ruggiero *et al.,* 2002). For instance, this study indicated that the soil textural classes for bottom and middle parts in area enclosure were almost similar which is predominantly sandy with clay contents ranging mostly from 40.5% to 44% clay. However, the textural class for the upper of the area enclosure with some *in-situ* rainwater harvesting methods was classed under sandy-clay loam as depicted in Appendix Table 4. Hence, the textural classes of the study soil were influenced by the topographical position though the influence was not pronounced between bottom and middle parts of the enclosure (Table 4). This concurred with the previous report of (Abule, 2003).

The variation in soil texture of the experimental sites indicates that soil texture can play a role in determining moisture availability which is very important for seedling survival in a certain region. This soil texture in turn could be influenced by soil and water conservation devices and natural slope gradient. The finer textured soils are usually higher in bases and provide a favorable nutrient supply for vegetation. The sandier soils are usually deeper and provide a more favorable root zone for tree seedlings (Troeh and Thompson, 1993). The differences in the silt, clay and sand contents of the different topographic positions indicate that the soil is derived from different parent materials which results in geological differences in the study area. So, water holding capacity is also vary with different parent materials.

The topographic position through its effects of exposing land to agents of erosion has an impact on variation in soil texture classes. Silt and clay size particles are more easily removed by agents of erosion than sand particles. High sand and low contents of clay and silt can therefore be expected in erosion susceptible parts of slope classes. As it was depicted in Table 3, there were an increment in percentage of silt and clay from the upper parts through enclosure to bottom area enclosure with selected IRWH practices. The low percentage of silt and clay in the upper parts might be due to the processes of erosion as a result of natural slope gradient which in turn affects SWC efficiencies in conserving and storing moisture.

Table 4: Means of soil physical parameters across soil depths and slope class of area enclosure with selected (IRWH) practices

Parameters	Soil depths				
	0-10 cm	10-20cm	20-30 cm	±SE	P-value
Clay (%)	33.17^{b}	36.3^{ab}	40.33^{a}	1.56	0.048
Sand (%)	54.17^{a}	48.17^{b}	46.83^{b}	0.987	0.0042
Silt (%)	12.67^{a}	15.5^{a}	12.83^{a}	0.97	0.15
Bulk density (g/cm^3)	1.46^{c}	1.56^{b}	1.66^{a}	0.01	0.0001
Parameters	Slope classes				
	Upper	Middle	Bottom	±SE	P-value
Clay (%)	25.3^{b}	44.0^{a}	40.5^{a}	1.53	0.0003
Sand (%)	65.33^{a}	43.5^{b}	40.3^{b}	2.09	0.0003
Silt (%)	9.33^{c}	12.5^{b}	19.17^{a}	0.81	0.0004
Bulk density (g/cm^3)	1.64^{a}	1.54^{ab}	1.49^{b}	0.034	0.045

Means with the same letter superscripts across the rows of each respective factor i.e. soil depths and slope classes in area enclosure with selected in-situ rainwater harvesting practices are not significantly different at 0.05 and/or 0.01 level of significance. SD= Soil depth, ns = non-significant at 0.05 and/or 0.01 level of significance, SE = Standard error of the mean.

4.2.1.2. Bulk density

Bulk density ranged from 1.64g/cm^3 in the upper part of the catchment to 1.49g/cm^3 in the bottom enclosure parts (Table 3). The three slope gradient classes were almost significantly influenced ($p<0.05$) by soil bulky density. The highest bulk density achieved for the upper parts might be due to risks of soil erosion and only left with very firmed or compacted cobles.

Furthermore, the higher values of soil bulk densities for upper parts areas relative to those of middle and bottom might be due to the lowest incorporation of organic carbon as also reported by (Pande and Yamamoto 2006). Loss of vegetative and litter cover coupled with rangeland degradation allows direct impact of rain drops on upper parts, resulting to enhanced splash impacts, mechanical crust formation, surface sealing, and may also produce hydrophobic substances that can reduce water infiltration into soil (Stavi *et al.*, 2008). This finding is also in accord with the results of Assefa (2004), who concluded that lands with a higher bulk density more than 1.6 g/cm^3 are not at acceptable level for plant root development to support cultivation.

5. CONCLUSION AND RECOMMENDATION

5.1.CONCLUSION

It can be concluded from this study that SWC methods are the most important in conserving and storing soil moisture as well as soil nutrients. It acts as a supplemental moisture and soil nutrients for seedling survival and growth. Thus, it has a potential to form a chief component in the rehabilitation of degraded land and forest establishment by facilitating favorable conditions for tree seedling survival and growth in Dryland areas where there is shortage of rainfall. But appropriate slope position and structure design play a crucial role in determining the amounts of moisture and soil nutrient to be conserved in and/ or around SWC structures. Estimating the number of tree seedling survivals will enable us to assess the efficiency of soil and water conservation measures in conserving and storing moisture and soil nutrients as well as status of land degradation. The main effect of *in-situ* rainwater harvesting structures on conserving and storing moisture was not significant except level soil bund embankment. Because the moisture conserved, in level soil bund is far from seedling roots which is below the requirement for seedlings to easily access.

Tree seedlings survived in the bottom parts where the soil is relatively better in moisture and fertile soil nutrient status and infiltration as compared to upper slope classes. Natural slope gradient determines soil physical properties which in turn determine the *in-situ* rainwater harvesting structures efficiencies. Almost all *in-situ* rainwater harvesting methods play a crucial role in conserving and storing moisture and soil nutrient which is essential at bottom or flat land rather than middle and upper parts of the catchment.

The seedlings that survived in half-moon at different parts of the catchment show highly significant differences at $p<0.05$ of bottom and upper parts and significant differences at $p< 0.05$ between middle and upper parts of the catchment. This explains that almost all *in-situ* rainwater harvesting methods play a crucial role in conserving and storing moisture and soil nutrient which is essential at bottom or flat land rather than middle and upper parts of the catchment.

5.2. RECOMMENDATION

Based on the findings of the study, it is recommended that future research and development studies and activities need to focus on the following recommendations. For the best results of tree seedling survival, the SWC suitability evaluation should be carried out in regard of slope, type and runoff storage capacity before seedling transplanting. Further investigation should be carried out on the factors contributing to low seedling survival, and appropriate techniques tested in order to recommend appropriate management interventions for tree seedling survival in moisture-stressed areas. Because, of the complex factors such seedling species type, external damage from termite impacts, nature of soil nutrient which is largely dependent on land-uses and topography additional research is needed in the Borana rangelands in this regards. This would help to understand biological and physical factors contributing to low seedling survival and recommend the way managing this area better.

The SWC devices potentials at three slope classes in this study were based on one seedling species data though seedling growth and survivals is spatially affected. Therefore, further study across seasons and years as well as different tree seedling species should be thoroughly investigated to capture the whole dynamics of the tree seedling growth and survivals including some tree seedling parameters such as tree height, DBH and vegetation biomass for different tree seedling species of the study zone in general need further investigation.

In this study, parameters such as slope class and soil characteristics were considered. On the other hand, parameters such as chemical compositions in relation to different SWC practices need to have further investigation. The only considered SWC system in this study were three soil moisture conserving and storing practices; however, for better understanding of the whole system other similar practices for example negarim, eyebrow, stone bunds and other biological rainwater harvesting system in the study zone in general need further exploration.

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APPENDICES

Appendix Table 1: Mean survival (%) of seedlings planted in infiltration pits at three classified slope classes

Quadrant No	Slope class I	Slope class II	Slope class III
Q1	53	39	14
Q2	53	39	19
Q3	60	35	19
Q4	64	41	24
Q5	64	41	25
Q6	69	41	25
Q7	69	44	25
Q8	69	50	25
Q9	69	50	26
Q10	62	50	26
Q11	67	50	26
Q12	67	53	26
Q13	75	53	33
Q14	75	53	33
Q15	82	53	39
Mean	66.53	46.13	25.66
CV (%)	11.71	13.68	23.64
P- value	0.0001	0.0001	0.0001

Means in columns with the same letters are not significantly different

CV=coefficient variation, slope class I = (0-5%), slope class II= (6-10%), slope class III= (>10%).

Appendix Table 2: Mean survival (%) of seedlings planted in *half-moon* at three Classified slope classes

Quadrant No	Slope class I	Slope class II	Slope class III
Q1	53	35	15
Q2	53	35	15
Q3	60	32	19
Q4	64	37	19
Q5	64	37	15
Q6	69	39	15
Q7	69	39	20
Q8	69	44	16
Q9	69	44	16
Q10	62	47	22
Q11	67	44	22
Q12	67	44	23
Q13	75	50	27
Q14	75	50	29
Q15	82	50	33
Mean	66.53	41.80	20.40
CV (%)	11.71	14.27	27.72
P- value	0.0001	0.0001	0.0001

Means in columns with the same letters are not significantly different

CV=coefficient variation, slope class I = (0-5%), slope class II= (6-10%), slope class III= (>10%).

Appendix Table 3: Mean survival (%) of seedlings planted in level soil bund embankments at three classified slope classes

Quadrant No	Slope class I	Slope class II	Slope class III
Q1	47	33	15
Q2	47	40	19
Q3	47	40	27
Q4	50	40	28
Q5	50	42	28
Q6	46	42	29
Q7	54	44	29
Q8	54	44	33
Q9	58	44	30
Q10	58	44	30
Q11	58	47	32
Q12	64	47	32
Q13	64	44	32
Q14	64	44	32
Q15	71	44	36
Mean	55.46	42.60	28.80
CV (%)	14.03	8.07	18.66
P- value	0.0001	0.0001	0.0001

Means in columns with the same letters are not significantly different

CV=coefficient variation, slope class I = (0-5%), slope class II= (6-10%), slope class III= (>10%).

Appendix Table 4: Textural classes for the three slope classes of area enclosure practices

Slope classes	Particle Size Analysis (%)			
	Sand	Silt	Clay	Class
	68	10	22	Sandy, clay, loam
	55	15	30	Sandy, clay, loam
	54	11	35	Sandy, clay, loam
	70	14	16	Sandy loam
	60	14	26	Sandy, clay, loam
	60	10	30	Sandy, clay, loam
	70	10	20	Sandy, clay, loam
	68	12	20	Sandy, clay, loam
	60	12	28	Sandy, clay, loam
	70	10	20	Sandy, clay, loam
	66	14	20	Sandy, clay, loam
Upper	60	10	30	Sandy, clay, loam
	48	10	42	Sandy Clay
	40	27	33	Sandy Clay
	40	10	50	Sandy, clay, loam
	52	13	35	Sandy, clay, loam
	42	16	42	Sandy, clay, loam
	40	21	39	Sandy Clay
	45	11	44	Sandy Clay
	36	20	44	Sandy Clay
	44	23	33	Sandy Clay
	36	28	36	Sandy Clay
	31	25	44	Sandy Clay
Middle	42	17	41	Sandy Clay
	55	10	35	Sandy Clay
	42	8	50	Sandy Clay
	43	8	49	Sandy Clay
	38	20	42	Sandy Clay

	37	13	50	Clay
	35	13	52	Clay
	45	13	42	Sandy Clay
	48	18	34	Sandy Clay
	39	9	52	Sandy Clay
	50	10	40	Sandy Clay
	47	19	34	Sandy Clay
Bottom	40	20	40	Sandy Clay

UDn= Upper slope class with its respective number of replication and soil depth; MDn = Middle slope class with its respective number of replication and soil depths; BDn = Bottom slope class with its respective numbers of replication and soil depths.