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# Implications of Watershed Management Practices on Water Availability Using Hydrus 1D Model in Aba Gerima Watershed, Upper Blue Nile basin, Ethiopia

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## STATEMENT OF THE AUTHOR

By my signature below, I declare and affirm that this thesis is my own work. I have followed all ethical and technical principles of scholarship in the preparation, data collection, data analysis and compilation of this Thesis. Any scholarly matter that is included in the thesis has been given recognition through citation.

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This is to certify that the thesis prepared by Tekuamework Fikadu, entitled; *implications of watershed management practices on water availability using Hydrus 1D model in Aba Gerima watershed, Upper Blue Nile Basin, Ethiopia* and submitted in partial fulfillment of the requirements of the degree of Master of Science (Water Resource Management) complies with the regulations of the university and meet the accepted standards with respect to originality and quality.

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## Abstract

### *Implications of Watershed Management Practices on Water Availability Using Hydrus 1D Model in Aba Gerima Watershed, Upper Blue Nile basin, Ethiopia*

*Tekuamework Fikadu*

Despite significant improvements in environmental protection and watershed management, there is still a problem of land degradation and natural resource depletion in Ethiopia. The main objective of this thesis was to assess the water availability implications of watershed management practices in Aba Gerima watershed, located in upper Blue Nile basin, Lake Tana sub basin, Ethiopia. Soil moisture, meteorological, ecological and ground water level data were collected and analyzed with Hydrus 1D model to estimate hydrological components such as surface flux, bottom flux, soil water storage, Evaporation, root water uptake and infiltration of each of the eight study sites. Based on this, the cumulative evaporation in 365 days for sites under controlled situation was 37.63% higher from that of sites under watershed management practices. Besides to this, sites under watershed management were better in water availability having respective 4.6 % and 12.5% higher surface and bottom flux than the sites under controlled environment. In terms of modeling efficiency, the model predicted results for all of the 8 sites in a very good precision, with $R^2$ values 0.73 to 0.853 and RMSE values ranging from 0.015 to 0.04. Simulated results were calibrated with inverse solutions of Hydrus 1D model. Daily in situ measured soil water content data in different layers of 400mm soil profile was applied for calibration. Therefore, the study concluded watershed management practices have positive implications in improving water availability parameters in Aba Gerima and suggested, every watershed should be treated according to appropriate management type based on detail study.

***Key words; Hydrus 1D, Water availability, Bottom flux, surface flux, Inverse solution.***

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## List of Abbreviations and Acronyms

| | |
|---|---|
| AC | Area Closure |
| ACE | Area Closure with engineering structures |
| AMSL | Above mean sea level |
| BD | Bulk density |
| CL | Cultivated Land |
| CLG0 (1) | Cultivated land under gentle slope and treated under WSM (controlled) |
| ClF0 (1) | Cultivated land under flat slope and treated under WSM (controlled) |
| CLS0 (1) | Cultivated land under steep slope and treated under WSM (controlled) |
| Cm | Centimeters |
| DEM | Digital Elevation Model |
| ENMA | Ethiopian National Meteorology Authority |
| EROS | Earth Resources Observation and Science |
| ET | Evapotranspiration |
| Ha | Hectares |
| ISODATA | Iterative Self-Organizing Data Analysis |
| KML | Keyhole Markup Language |
| LULC | Land Use Land Cover |
| M | Meters |
| Mm | Millimeters |
| NASA | National Aeronautics and Space Association |
| OLI | Operation Land Manager |
| SL | Soil Loss |
| SLM | Sustainable land management |
| SM | Soil Moisture |
| SWC/SWS | Soil water content / Soil water storage |
| SRTMGL1 | Shuttle Radar Topography Mission Global 1 |
| USDA | United states department of agriculture |
| USGS | United States Geological Survey |
| WLRC | Water and Land Resource Center |
| WSM | Watershed management |
| WS | Watershed |

# CHAPTER ONE

# INTRODUCTION

## 1.1.Back ground

Watersheds are biophysical systems that define the land surface that drains water and waterborne sediments, nutrients, and chemical constituents to a point in a stream channel or a river defined by topographic boundaries. It's also defined as the surface landscape systems that transform precipitation into water flows to streams and rivers, from these most of which reach the oceans. Watersheds are the systems used to study the hydrologic cycle and they help us understand how human activities influence components of the hydrologic cycle (Brooks et al., 2003). It is believed that Ethiopia has huge potential of water and land resources which is comfortable for agriculture to achieve food security. The country has 12 basins from which eight river & one lake basins with annual runoff volume of 124.4 billion $m^3$ of surface water (Berhanu et al., 2014) while various scholars estimated different values for groundwater potential & according to Mengistu et al. (2019) 40 billion $m^3$ has been estimated. However, the country continued to be food insecure and unable to irrigate over 5% (1850 $km^2$) of the potential irrigable area (Awulachew et al., 2007; Wale et al., 2009). While, the Ethiopian highlands are contributing more than 80% flow to Nile River, only a tiny portion of the Nile water is being used in Ethiopia for irrigation (Wale et al., 2009). In the contrary, the problem of land degradation is typical of the Ethiopian highlands (Herweg and Stillhardt, 1999). The combined effects of deforestation, overgrazing and agricultural expansion, un sustainable use of natural resources, fragile soils, undulating terrain, and heavy seasonal rains make the Ethiopian highlands vulnerable to soil erosion by multiplying surface runoff and decreasing recharge and soil fertility (Schmidt and Zemadim, 2015).

About 80% of the current world's land degradation of agricultural land is caused by soil erosion (Angima et al., 2003). At a global scale, Erosion caused by water is the leading soil degradation factor in agricultural areas (Bewket and Sterk 2002).

Land degradation and its consequential impact on agricultural productivity and food security was a global challenge for many decades (Morgan, 2005) and continued being an important issue in the 21 st century (Ademe et al., 2017). Now days there are huge movements seen in Environmental protection, soil and water conservation and other related issues. Over the last three decades, huge investments and substantial resources was applied on this area to develop and promote sustainable land management practices as part of efforts to improve environmental conditions, ensure sustainable and increased agricultural production, and reduce poverty by the government of Ethiopia and local or international donors (Herweg and Ludi, 1999; Adgo et al., 2013; Adimassu et al., 2014; Amare et al., 2014; Haregeweyn et al., 2015). Arable land and water resources are becoming scarcer with the earth's expanding population of people. These scarcities and the human responses to these scarcities pose challenges to sustainable development and can have serious environmental consequences. Changing climatic conditions and weather patterns add uncertainty to future land and water resource management. It is unclear where and how much the supplies of freshwater will change with changes in climate and weather. What is clear, however, is that the increasing water demands caused by increasing populations of people and expanding economic developments will pose far greater problems by the year 2025 than currently (Vorosmarty et al., 2000). Watershed management has clear impact on how we utilize our water and land resources and availability of those resources in the specified watershed which has also its own implication on water and food security of the community.

For countries like Ethiopia which their policies of development focus on water resource potential as a core, Water security is basic for energy security, food security and sustainable economic growth (Berhanu et al., 2014). Ethiopia is known to be water tower of east Africa and Abay river basin is one of the major river basins in Ethiopia that contributes most of the water for Nile river (Awlachew et al., 2009). Even though, the country has enormous amount of water resource potential, Seasonal _spatial variability in rainfall coverage and depth makes it difficult to distribute the resource fairly in a balanced amount (Berhanu et al., 2014). This distribution variation causes drought in some areas and flooding, landslide, soil erosion, and land degradation in other areas or watersheds.

Watershed management implies an efficient consumption of natural resources to ensure the optimum and sustained outcome." Watershed management practices are those changes in vegetative cover, land use, and other nonstructural and structural actions taken on a watershed to achieve watershed management objectives"(Brooks et al.,2003). Even though it's not enough, there have been so many soil and water conservation work done as a part of watershed management practices to utilize resources in a manner that can use for the people without damaging the environment in Ethiopian plateau highlands (Sultan et al., 2018). Particularly in areas like our study watershed, with widespread high sheet erosion, land degradation and poorly managed water resources those watershed management practices are essential as a solution for the mentioned problems (Berihun et al., 2019; WLRC, 2012).

Aba Gerima watershed is one of many smaller watersheds found in Abay basin, Lake Tana sub basin in the North western plateau of Ethiopian highlands around Bahr dar town (WLRC, 2012). As a part of Nile river basin, it's characterized by high population growth rate and demand of resources, high soil erosion and land degradation, decreasing potential of water resources due to mis consumption and high competition for resources becomes the identities of the watershed. Studies agree on that extreme poverty, food insecurity, water shortages, land degradation, pollution from effluents and the potential for acute water conflict will be current and future challenges that have been facing on water management in the Nile basin (Awulachew et al., 2012). So, overall Cooperation is recommended to manage and develop watersheds, prevent land degradation, improve water availability/quality, maximize the resource and minimize negative impacts for best achievement to enhance water security of peoples.

Some written and oral information about history of land use in Aba Gerima watershed reflects there was huge soil erosion and Land degradation before the implementation of watershed management practices before 2012 (WLRC, 2012). In addition to intensive cultivation in a traditional way, deforestation in all land features torrential and erratic rainfall causes high soil erosion and land degradation in the area. The soil erosion in the area was as severe as majority of the land has very thin soil cover especially, shrubby and bushy lands, in a hilly terrain, exposed parent material is exposed to the surface. During the time of the survey land degradation and soil erosion caused by high deforestation was observed. However currently, this form of land degradation is very rare since the extent of the damage gone to the extreme and majority of the natural vegetation is already lost. Degradation of the quality of land is the current problem that is affecting the community severely. The hilly terrain of the watershed is still under pressure of Physical land degradation where the land is highly disgraced and become devoid of vegetation. Gullies being formed due to soil erosion by running water is commonly observed on grassland where there is over grazing exercise has been applied mainly due to week common grazing land management.

Sheet and rill erosions highly affected the soil of the watershed particularly on steep slopes.

Since practically no one was responsible to take care of grass lands mainly the communal ones are affected by gullies severely. The hills especially near Kacha, Diljamie and Laguna Giorgis villages were highly affected by sheet erosion that largely reduce products and productivity of the soil than affecting the environment in a physically visible manner. Since the soil cover is highly eroded with water erosion, Areas around Giorgis church, Yijaji hill and Dekama mekemecha villages of the watershed have covered with higher percentage of stone cover. The wet lands known at Tach Kacha, and Tach mender villages and Yidemo river surroundings were converted to farm lands during the survey time (WLRC, 2012).

The watershed management work launched in 2012 was a turning point to improve natural resources potential and productivity of the watershed. It has had totally changed the area in to fully recovered state until some turning back symptoms because of poor and an organized management of the watershed just after the watershed management project has being stopped. Therefore, most terraces have damaged, area closures abandoned from conservation and there are also the signs of gully formation in some areas.

So,This study examined whether watershed management practices done in Aba Gerima watershed has a significant implication on water availability in the area during the study period or not?" with Hydrus 1d model simulation of study sites. In the study, the implication of watershed management practices on soil physical properties has been studied with respect to soil hydraulic properties.

## 1.2. Statement of the problem

Watershed management practices are nonstructural and structural actions taken on a watershed to achieve watershed management objectives or increase productivity of the watershed (Brooks et al., 2003). Watershed management practices can influence LULC of a watershed directly or indirectly. Unfortunately, LULC type change is one of the major factors to influence water resource potential of the area (Berihun et al.,2019). Watershed management can also contribute significantly to earth–atmosphere interactions, forest fragmentation, land degradation, and biodiversity loss (Haregeweyn et al., 2015; Maitima et al., 2009). The Ethiopian Government and various donors have invested considerable amount of investments over the past three decades in establishing and supporting sustainable land management practices as part of efforts to improve natural environment, ensure food security and poverty reduction (e.g. Herweg and Ludi, 1999; Adgo et al., 2013; Haregeweyn et al., 2015). As part of watershed management practices, physical structures like Short trenches, soil and stone bunds, cut-off drains, check dams, hillside terraces, area closures have been combined with biological measures such as vegetation establishment can be applied on a watershed to prevent soil erosion and its consequences (Amare et al., 2014). These watershed management activities have been also applied on Aba Gerima watershed which is a part of Lake Tana sub basin and Abay basin to prevent soil erosion and land degradation as well as enhance water availability (Berihun et al., 2018; WLRC, 2012). However most of the promoted activities have been only marginally effective due to low rates of adoption. Dis adoption or decreased use of the techniques has been documented in some cases (Tadesse and Belay, 2004).

Many researches carried out regarding watershed management and LULC modifications on a global scale have clearly demonstrated the expansion of cultivated land at the detriment of natural forests. Increase in agricultural land area and decrease in forest and bush land affect the area's distribution of ground and surface water supplies by increasing surface runoff that aggravates gully formation through erosion. According to studies, major LULC changes were observed since the late twentieth century in various parts of Ethiopia through deforestation and reforestation activities (Bewket. 2002). In particular, studies focusing on the Ethiopian highlands have shown that the expansion of agricultural land at the detriment of natural forests has increased over time (Betru et al., 2019). Besides to increasing water demand to meet high population growth, Aba Gerima watershed has been facing high scarcity of water for commercial farms mainly for khat due to backward irrigation system and poor watershed management (WLRC, 2012). It’s also usual to observe sheet erosion and gully formation in different areas of the watershed.

This observed water scarcity which can anytime grow to water stress, can only be mitigated and solved by ensuring water security through application of effective watershed management and environmental protection practices. Various Researches has been conducted (Eg. Berihun et al.,2019; Mekonin et al., 2011) and watershed management practices were applied in Aba Gerima to enhance overall productivity of the watershed including water and land resources. So, this study mainly focused on the implication of those watershed management practices on the availability of surface and ground water in Aba Gerima throughout the study period. This study was mainly carried out through comparing water availability of controlled sites with other similar sites under watershed management practices. Hydrus 1D modeling of water balance components were the technique applied to examine the availability of water in the watershed within the study time.

## 1.3. Research objectives

### 1.3.1. General objective

The general objective of this thesis was to examine the water availability implications of watershed management practices carried out in Aba Gerima watershed so far.

### 1.3.2. Specific Objectives

The specific objectives of this thesis work were

1) To analyze observed soil physical and hydrological properties in each of the individual study sites within the study period.
2) To estimate different water balance components and hydrological parameters using Hydrus 1D model simulation under different WSM practices in Aba Gerima watershed.
3) To evaluate the implication of sustainable watershed management practices on the study sites hydraulic properties.

## 1.4. Research Questions

The research focuses mainly on answering the main research question stated "How does sustainable watershed management practices contribute to water availability of Aba Gerima watershed within 365 days study period"?

Specifically, this thesis addressed

1) Is there a significant impact that soil physical properties made on soil hydrological properties in each of the individual study sites within the study period?
2) Is there a significant difference in water availability of the study sites under different land management systems (i.e. controlled versus under WSM practices) within the study time frame 365 days?

## 1.5. Significance of the study

Whilst the general implications of sustainable land management and watershed management practices have been well studied previously, it's rare to find researches that document the implication of watershed management practices on water availability in small watersheds like Aba Gerima. However, the scarcity of baseline document, well organized data and adequate amount of researches in the area makes different research institutions, policy makers and project implementers to face difficulties in finding such documents for reference & decision making.

Therefore, the study has significances in (1) supporting as a baseline or an input reference document for other similar studies and policy/ proposal developments to be done in the future in Aba Gerima or other similar watersheds. (2) Providing organized data related to soil properties, Vegetation cover, land use, Temperature and rainfall data for the study area in the study time frame. (3) Indicating areas of investment for watershed management especially water and land resource management to effectively implement water security related projects like ground or surface water resource development projects. (4) Motivate other researchers to do their research on that area mainly in detecting environmental changes regarding degradations like ground water depletion, flooding and erosion.

## 1.6. Scope and limitation of the study

This thesis work was planned to provide its own contribution to study the implication of watershed management practices on water availability in the 900 ha wide Aba Gerima watershed, located in Bahrdar zuria woreda, western Gojam zone of Amhara region. One dimensional water flow model was applied to simulate water balance components of those study sites sampled for 400mm depth soil profile. The study was conducted in 8 experimental sites under different watershed management practices. Watershed management type, slope, soil type & properties, max-min daily T, average daily Ppt, Ground water level data has been observed & studied for a year to estimate water availability for treated & untreated sites in Aba Gerima watershed.

Therefore, the scope of this study was to address how much implications do watershed management practices has on water availability of the study sites in Aba Gerima watershed through Hydrus 1 dimensional water flow model under different WSM practices within 365 days. Water availability was explained interms of surface flux, soil moisture, infiltration, bottom flux, evaporation and root water uptake within the study period for those eight selected experimental sites in sites under WSM & controlled environment.

The following points were also the main constraints to conduct this thesis.

(1) Availability of collected and well organized data in the area (i.e.; - data such as ground water data, climate data, and stream discharge data.) Some of the collected data such as ground water level data & depth of watershed management works done has been surveyed & collected with too much effort within very limited time

(2). Scarcity of well-organized stream discharge data limited the flexibility to consider other Hydrological models. However, the selected Hydrus 1D model which's a precice model to run and analyze 1 dimensional flow of water using the available collected data such as soil moisture data for calibration.

(3) Since all models are not accurate in representing the real world situation, the selected model might have limitations on describing the real ground condition, However, in this study different data has been checked, various literatures in the area has been referred and repeated field observations has been made during the study to secure the reliability of the results.

# CHAPTER 2

# Literature Review

The difference in productivity of the watershed between treated and untreated land surface is not questionable. Negative implications of LULC change caused by high growth of human demand due to large population growth highly affect the earth environment to be degraded (Bewket & Abebe ,2013). There are so many researchers conducted to analyze the role of watershed management in controlling natural environment in a manner that can sustain its productivity and offer maximum benefit without harming the environment (Alemu & Kidane, 2014, Gashaw, 2015). Water and land resources are the two major components of a watershed. From any other components, watershed management practices have more direct implementations on land and water. There are so many mathematical and conceptual models applied to study land and water resources in the watershed or basin level. According to Singh & Frevert (2003). Watershed modeling bargains with modeling of all of the hydrologic forms at the watershed scale and joining them in arrange to decide the watershed reaction. The accentuation here is on the models that finish this integration, not on the models of person component processes. Various models of Land and water management have been applied worldwide to simulate watershed water and land resources variations. In this study Hydrus 1d model which is one dimensional water flow simulation model has been applied to evaluate water balance components in each of the selected study sites in Aba Gerima watershed. Based on this, some literatures have been organized around the ideas of watershed management, water security, and hydrology or water balance, hydrological models including some GIS concepts as a theoretical base to conduct the study on the implication of watershed management practices on water availability of Aba Gerima watershed.

## 2.1. Watershed management Practices

According to Brouziyne et al. (2018) watersheds are, defined as study units to assess hydrological cycles and come up with water management strategies. The article included, the watershed is also taken as the planning unit for reasonable management of natural resources, within vital strategic and political actions plan. The common and representative behavior of all watersheds is that they hold numerous interrelated natural resources like soil, water, vegetation and impact on one resource perpetually affects the existence of the others (White, 1992). There are so many processes taken place in a watershed including natural Water cycle process which depends up on various biotic and climatic factors that can facilitate or hinder the flow process in its different modes. Watershed management is an activity to manage natural resources within the watershed in a manner that can give maximum benefit without harming an environment. According to Shen (1990) Watershed management is the act of deriving and carrying out a course of action to gain maximum benefit of supply without adversely affecting the soil and water resources. As that of globally studied researches, studies in Ethiopia elaborate that on-site implications of natural resource management in the watershed on soil loss, sediment yield, discharge, land cover and productivity (Adimassu et al., 2016; Ebabu et al.,2019; Kassawmar et al.,2018).

Watershed management practices can be defined as land management practices conducted in a watershed that provide sustainable economic, environmental and social importance. Watershed management is an organized and planned usage of land and resources in the watershed to address continuously changing basic human needs water-soil interactions in the Earth's system is determined by soil hydrology specifically, soil acts as an interface within the atmosphere, biosphere and lithosphere, and regulates main processes of the hydrosphere as runoff discharge, aquifer recharge and soil water content. Lozano-Parra et al. (2015) investigated interactions between soil moisture and vegetation covers implications on soil temperature. The study monitored two and a half hydrological years of soil water content and soil temperature of open grasslands and below tree canopies. Results obtained revealed that rainwater amounts reaching the soil may temporarily be modified by covers according to precipitation properties and antecedent conditions (from dry to wet) before the rain episode.

Various governmental and NGOs contribute in many watershed management related processes and practices in various parts of the world. Including Ethiopia, in various countries and regions watershed management practices highly promoted to support the scaling up Land management, Environmental protection and resource management project activities. As a part of this, there has been also so much effort applied in Aba Gerima watershed to maximize land and resources productivity since 2012.This includes major watershed management practices including reforestation, area enclosure, terracing, contour bounds, tillage, crop rotation and other bio engineering mechanisms and methods.

In the gentle and steep slopes of Aba Gerima watershed there are too much efforts applied in area enclosure and construction of terraces, trenches, stone bounds and different biophysical measures to protect the land from degradation. The result has been clearly visible through reforestation of the degraded area since 2012 and the implications of those works manifest itself in different economic, social and environmental improvements of the livelihood in the watershed. The main target of those watershed management practices in the watershed includes practices to prevent land conversion and protect vulnerable lands; prevent and mitigate land degradation and restore degraded soils; control soil erosion; improve soil-water storage; manage soil organic matter for soil carbon sequestration; manage and enhance soil fertility; promote integrated soil–crop–water management and integrated agroforestry and pastoral systems; rehabilitate and sustainably manage dry land environments (e.g. managing grazing and livestock; rainwater harvesting; sand-dune reclamation; oasis management; drought management; and precision agriculture).

## 2.2. Water availability

Water is a basic natural element that’s fundamental for existence of life on the earth. It’s found in different forms as solid, liquid and gaseous state. Hydrological cycle describes how water is available in different forms through Earth's land, ocean, and atmosphere. Water resources availability varies spatially and temporally due to climate and topographic factors. Therefore, Hydrological cycle is the link that interacts availability of different forms of water in different spatial and temporal existences like the atmosphere, lithosphere, biosphere and anthroposphere. It is also profoundly affected by human activities and socio-economic development (Yang et al, 2021). Cyclic nature of water resource made water renewable resource. However water cycle is a basic governing rule in the distribution and availability of water throughout the Medias of the earth as the water balance law states the inflows to any water system or area is equal to its outflows plus change in storage within a time interval (Viessman & Lewis, 1996)._*Introduction to Hydrology* (Fourth ed.). It’s also widely observed that recent fast climate and land use alterations in the globe, the global hydrological cycle is too much affected spatially and temporally, manifested in various water-related issues that brought water security related challenges to humans. Therefore, advancements in the field of hydrology especially improvements in the area of the hydrological cycle, water balance and water resources has become a key focus area in researches regarding environmental and natural resources ( Wang et al., 2010a). So, familiarity with water balance and watershed level management of water resource might be very important to overcome challenges in water security. The water balance equation used to determine available water in a system is represented by;

Water in= water out + change in storage

In the study of water availability, each component of the water balance in a hydrologic cycle would be studied according to the concern of the study. Eq 2.1 represents the relation between water balance components;

$$\mathrm{SS} = \mathrm{WI} - \mathrm{RO} - \mathrm{ET} - \mathrm{L} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

where, SS; available soil storage (cm); WI; the amount of total input water (cm) rain gauge recorded; RO; the amount of water flow as runoff from fields (cm) estimated from water balance equation; ET; Evapotranspiration (cm) estimated from Hargreaves equation; L; the amount of leached water (cm) calculated using the equation.

Water availability is also denoted as occurrence and distribution of water in a system in different scales. Water can be available in a global, large basin, small watershed and other minor scales. Precipitation is the main source of water in the watersheds. Hydrological cycle represents the process how the water comes from precipitation interacts with the environment and occur in different forms in a system (Edwards et al., 2015) According to Oki (1999) water in the globe has been distributed in different forms of fluxes such as surface run off, evaporation, transpiration, soil water storage ground water recharge. In a global scale, trees with a minimum 510 mm diameter transpired 265 liters per day in an average (Wullschleger et al. 1998). Edwards et al. (2015) described Evaporation and transpiration as a negative processes that the water precipitated in the watershed escaped out in different form. According to Wilson & Luxmoore (1988), larger size pore spaces in soils and rocks transmit water unlike to micro pores that store moisture that stored within the soil profile. However, bottom flux or ground water recharge is denoted by water that passed through macro and meso pores of the soil profile towards the water stored beneath the soil layer within under laid rocks (Edwards et al., 2015). There might be interaction between ground and surface water in both directions that ground water might feed Surface fluxes and surface stream flow /ice melt can recharge the ground as bottom flux (Foster & Allen, 2015). This study in Aba Gerima watershed was also followed the way of estimating each component of hydrological cycle to detect the impact of watershed management practices on water availability in the watershed.

## 2.3. Impact of watershed management practices on water availability

According to Wani & Garg (2009) watershed management is a collective and integrated action of land water conservation, nutrient and pest management, increasing crop type and quantity with creating social potential/build capacity/. Inappropriate changes in land use due to anthropogenic causes are a common problem that may result land degradation (Celik, 2005). Various types of watershed management practices can have number of impacts on Soil physical properties and structure (Sharma & Aggarwal, 1984). Soil disturbance is a sensitive parameter that can affect Soil hydraulic properties (Schoenholtz et al., 2000). So, WSM practices that incorporate managing land resource are decisive factors to influence soil moisture and other hydraulic properties. According to Haghighi et al. (2010), land use has had significant impacts on bulk density and saturated hydraulic conductivity (Ks).

In a watershed level, the conversion of one land use type to other have had its own impact on soil water content and other hydraulic characteristics. For example, conversion of pasture to cropland will result in decrease in soil organic matter (SOM) content, aggregate stability and saturated hydraulic conductivity (Celik, 2005). In the same way decreasing of the rate of soil water infiltration and increasing in erosion enhancing soil physical characteristics might be resulted from the conversion of natural land into cropland (Li et al., 2010). These Land use changes reduce SOC in the meantime soil aggregate stability will be also decreased and leads to soil degradation (Wu and Tissen, 2002). Soil Organic Matter is a major factor in the keeping soil aggregate stability and increase water retention and infiltration (Gregorich et al., 1994). Therefore, WSM is an important area of investigation to manage land use in a watershed towards it can positively influence soil hydraulic properties and the hydrological cycle components that enhance water availability.

According to Rodriguez Iturbe et al. (1999) Soil water (i.e. soil moisture) content is one of the main factors that affect vegetation cover structure in water scarce environments (in the reverse, vegetation has also huge role in controlling the whole water distribution (Rodriguez-Iturbe et al., 2001) through much interacted, mutually influencing water cycle processes (Porporato et al., 2002). Land use affect significantly soil properties like saturated hydraulic conductivity, infiltration rate, bulk density, and available soil water (moisture) content (Haghighi et al., 2010). Since soil properties have huge impact on influencing soil water variations (Vachaud et al., 1985), land use could also influence soil water through affecting soil properties (Gao et al.,2014). In addition to soil moisture content watershed management practices have its own impacts on Surface and bottom fluxes like surface run off, recharge and ET through changing the watershed in terms of soil property, biodiversity and cover, morphology and aspect (Edwards et al., 2015).

## 2.4. Watershed management practices in Aba Gerima watershed

Likewise most small watersheds in the upper Blue Nile basin Aba Gerima was a highly degraded watershed due to unwise land management and resource utilization (WLRC, 2012). Besides to high ground water abstraction through hand dug wells for khat irrigation most parts of the watershed were vulnerable for sheet erosion and gully formation. According to Sultan et al. (2018) various types of watershed management practices has been launched with different governmental and non-governmental fund sources to improve the productivity of the watershed and rehabilitate the damaged environment. Those practices include area enclosures, biological measures and construction of physical soil and water conservation structures (Haregeweyn et al., 2015). Sultan et al. (2018) describes the physical WSM works as soil walls of about 0.5–1.0 m high were built to construct soil bunds and Fanya juu along contours; Soil faced short trenches with 0.5 m depth, 1.4 m width, 1.5–2.5 m length and 1.7 m spacing between trenches along the contour. From our field observation in 2021 also, there has clearly visible that these structures at the side of the slope, between farm lands and combined with area enclosures. These watershed management activities have brought significant change for Aba Gerima watershed in preventing soil erosion, land degradation, ground water depletion and surface water resource improvement (Berihun et al., 2018; Sulatn et al., 2018). However, the absence of establishment of strong watershed level administration, consistent and sustainable monitoring and evaluation system added on low consciousness of the community about the benefits of WSM made those best results to be going back to the early unmanaged conditions. From our field observation so many soil and water conservation structures has damaged and area enclosures abandoned to grazing. Plates (i to iii) can describe the degree of damage in some of the watershed areas that was managed before. This thesis was conducted mainly based on this gap to estimate the implications of these WSM practices on water availability of the watershed through available data.

## 2.5. Hydrus 1D Hydrological model

Studying hydrologic cycle (especially in watershed scale) can be achieved by assessing all interacting components or factors in the hydrological cycle like soils, topography, vegetation cover, climate, water bodies...etc., ideally under an integrated approach. The interaction of environmental constitutes can be represented by hydrologic models which can describe and estimate real hydrological systems in a simple precise manner. Models are the best tools to study a hydrologic system such as a basin through input and output data leading to a better understanding of the physical and hydrological processes that take place in the basin. The main purpose behind the use of models is to simulate part of the reality at the best possible approximation; many of conceptual models are useful for understanding a particular problem or for predicting future behaviors of a system. In a modeling project, the main and basic step is selection of the right type of hydrologic model type and tool according to the objective of the study project. According to Burges (1986) Hydrologic modeling is mainly applied in finding solutions for environmental problems interms of the quality or quantity of water in a hydrologic system such as mini catchments, a watershed or river basin. Hydrological modeling is also described in the paper Brouziyne et al. (2018) as a tool that can offer the chance to achieve water management strategies and goals.

HYDRUS-1D is a model that can simulate uni-dimensional water flow in variable saturated porous media. It’s a Microsoft windows based hydrodynamics model programmed to simulate water flow and solute transport in porous, permeable media. This model has been successfully used to simulate water flow in different studies and researches. The soil water equation applied in HYDRUS-1D model is the Richards equation

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left[K\left(\frac{\partial h}{\partial z} + \cos \propto\right)\right] - S(h) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.2)}$$

Where t is time in days, θ is volumetric WC in $mm^3/mm^3$, h is water pressure head (mm), z is vertical axis/depth in mm, K(h) is hydraulic conductivity in mm/day, and S(h) is water sink term measured in mm/day. The van Genuchten- Mualem equation (VanGenuchten et al., 1980) models the variation of K(h) with soil water content. Rosseta 1.0 with textural composition of the soil sample sand, silt, clay, bulk density model has been applied within neural network prediction method to estimate soil water content from soil hydraulic properties and meteorological data provided.

$$\theta(h) = \theta_r + \frac{(\theta_s - \theta_r)}{[1+(\alpha h)^n]^m} \ , h < 0 \ldots\ldots \tag{2.3}$$

$$\theta(h) = \theta_S \ , h \geq 0 \ldots\ldots \tag{2.4}$$

$$K(h) = K_s S_e^1 \left[ 1 - \left( 1 - S_e^{\frac{1}{m}} \right)^m \right]^2 , K(h) = K_s \ for \ h \geq 0 \ldots\ldots \tag{2.5}$$

$$S_e = \frac{(\theta + \theta_r)}{(\theta_s - \theta)}, \text{for} \ldots . \mathrm{m} = 1 - \frac{1}{n}, \mathrm{n} > 1 \ldots\ldots \tag{2.6}$$

Where, $\theta_r$ and $\theta_s$ are residual and saturated water content, respectively, $K_s$ is saturated hydraulic conductivity, $S_e$ is effective saturation; empirical coefficients which are α, the inverse of the air-entry; distribution of pore-size index, n and parameter of a pore-connectivity, l. The sink term S(h) in Equation (3.7) is actual root-water uptake (equal to actual transpiration), obtained from the Feddes equation

$$\mathrm{S}\ (\mathrm{h}) = \propto (h) * b(z) * T_P \ldots\ldots \tag{2.7}$$

Where, α (h) is root-water uptake stress response function is a function of the soil water pressure head h ($0 \leq \alpha(h) \leq 1$) which is dimensionless, b(z) is normalized root-water uptake distribution, and $T_p$ is potential transpiration rate. The potential evapotranspiration ($ET_p$) was calculated from Equation;

$$ET_P = ET_0 * K_C \ldots\ldots \tag{2.8}$$

Where, $ET_0$ is reference evapotranspiration (mm/day), Kc is crop coefficient, which can be obtained from previous study. Potential evaporation ($E_p$) and potential transpiration ($T_p$) were parts of $ET_p$. This partitioning was achieved using crop leaf area index (LAI) based on Beer Equation, where c is empirical parameter

$$E_P = ET_P * e^{cLAI} \ldots\ldots \tag{2.9}$$

$$\mathrm{Tp} = \mathrm{ETp} \times (1 - \mathrm{e}^{-\mathrm{cLAI}}) \ldots\ldots \tag{2.10}$$

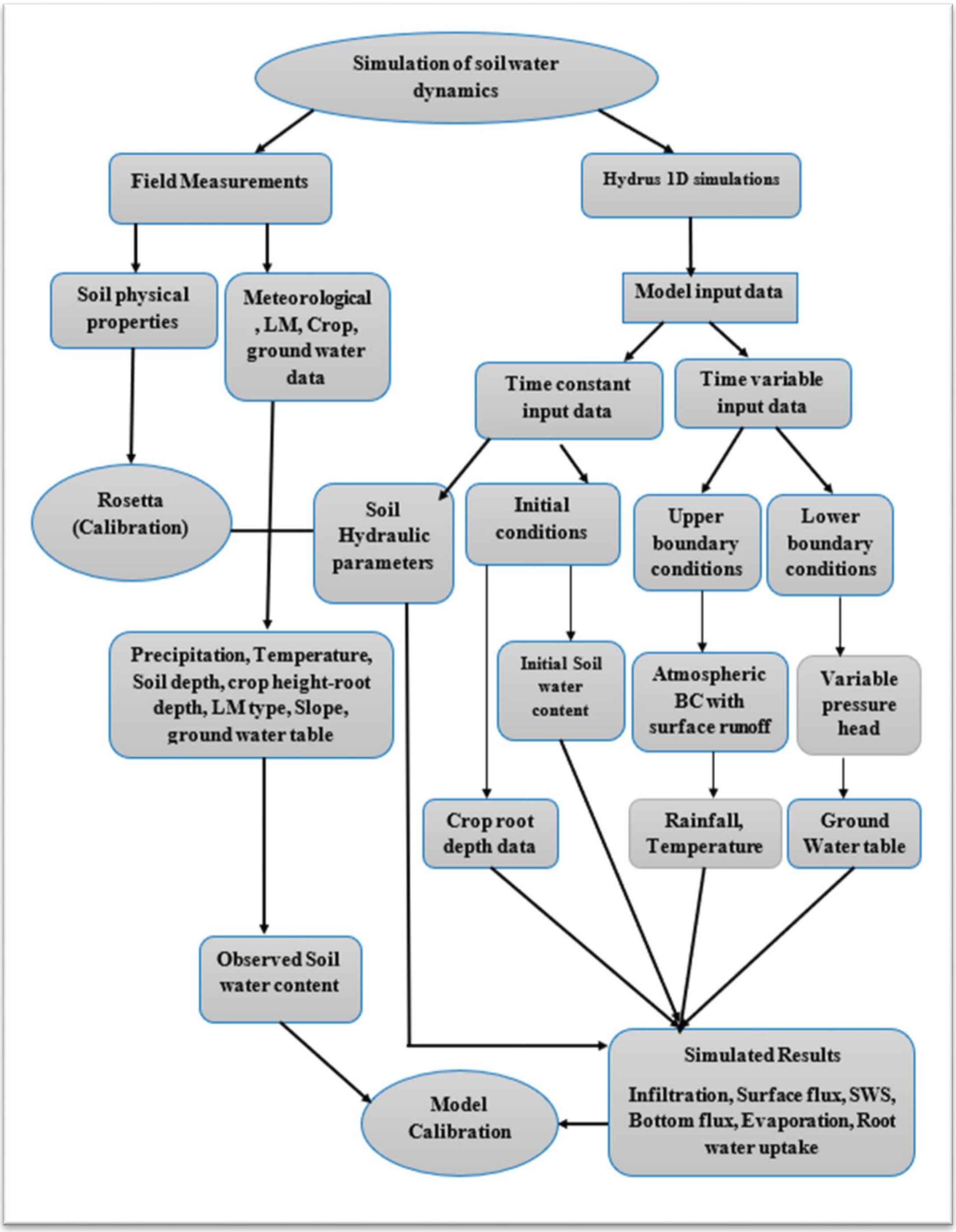


Figure 1. Model simulation process and calculation of water balance components in Hydrus 1D

## 2.6. Previous works

Many studies were carried out in various spatial and temporal scales to examine the relationship between WSM and its implications on Environment. Many of those focused on the effect of WSM on LULC and its implication on water availability, sediment loss and soil quality (E.g; Berihun, et al., 2019; Sultan et al., 2018)

According to Berihun, et al.(2019) on the study to explore LULC changes, causes and their implications in contrasting Agro-ecological environments of Ethiopia examined the trends, driving factors, and implications of LULC dynamics within 35 years study period (1982–2017) in three watersheds representing different agro ecologies namely Guder (highland), Aba Gerima (midland), and Debatie (lowland).

The study examined the effect of different LULC changes on the environment, socio economic setting, and water security of the watersheds. The changes in LULC were analyzed by integrating field observations, remote-sensing data (aerial photographs [1: 50,000 scale] and very high resolution [0.5–3.2 m] satellite images), and geographic information systems. The drivers of LULC were explored using key informant interviews and relevant literature reviews. Even though the study covers wider topics, detection of LULC changes in Aba Gerima watershed to examine the effect of watershed management practices on water security is the key point for our study on water availability in the watershed. The methodology applied in the study is integration of GIS techniques of change detection and LULC classification within field observation and key informant discussions. This is a well-known approach to study watershed land use land cover and its implications within a specified time range. The output of this study for Aba Gerima watershed revealed that forest land was the dominant LULC class accounting for 32.0%, in a year 1982. It’s described that Population growth and associated changes in the farming practices were the major driving forces for LULC changes happened in the study watersheds to decrease forest area and increase in cultived land. That expansion of cultivated land was the major driving factor to increase gully erosion and surface runoff potential of the study watersheds particularly, Aba Gerima and Debatie watersheds.

From the maps prepared to examine LULC changes in Aba Gerima watershed for the years 1982, 2005, and 2016, it’s clearly visible that the following four major implications of LULC changes has being examined. (1) Implications on soil erosion, (2) surface runoff response, (3) socio economic and (4) Environmental implications.

This might include the variation of runoff coefficient between cultivated land and vegetation cover across the watersheds. So, the observed LULC changes at the study watersheds have a notable influence on the surface runoff response. Other Socio economic and environmental implications of LULC changes are also discussed in the paper even though it has limitations on discussing each implication specifically in detail in our case water security. In addition to this, watershed management practices which are the main driving factors of LULC change also did not get much concern in the paper to focus on them.

Another study by Ebabu et al, (2019) Understanding the effect of land use and watershed management practices on runoff and soil loss (SL) describes the effect of those practices on soil and water of the study area. The study aims to analyze runoff and Soil Loss from different land use types and evaluate the effectiveness of different watershed management practices. This was done through monitoring runoff and sediment from 42 runoff plots (30 m × 6 m) in different agro-ecologies of the Upper Blue Nile basin of Ethiopia. Four treatments for croplands (control, soil bund, Fanya juu, and soil bund reinforced with grass) and three treatments for non-croplands (control, exclosure, and enclosure with trenches) were investigated during the rainy seasons. As a result, the runoff and Soil Loss highly varied depending on agro-ecology, land use type, and watershed management practices. With Seasonal runoff ranged between 52 to 810 mm in 2015 and 37 to 898 mm in 2016, Soil Loss ranged from 0.07 to 39.67 t ha−1 and 0.01 to 24.70 t ha−1. Untreated grazing land shows the highest rates were observed from in the midland agro-ecology heavy grazing and the occurrence of intense rain events might be responsible for the result. Both Runoff and Soil Loss significantly higher (P b 0.05) in control plots than in plots under watershed management practices. On average, seasonal runoff was reduced by 11% to 68% and SL by 38% to 94% in plots under watershed management practices. Watershed management practices like Soil bund reinforced with grass in croplands and enclosure with trenches in non-croplands give excellent outputs for reducing both runoff and Soil Loss. Application of Engineering and biological measures together was the best way to control soil erosion and land degradation. The paper recommends Additional investigation in consideration of ecological succession and other effects of those integrated measures, for example, the effects on soil properties, biomass, and biodiversity.

The study made on Efficiency of soil and water conservation practices in different agro-ecological environments in the Upper Blue Nile Basin of Ethiopia by Sultan et al, (2018) High spatial variation of runoff has being observed within and between land use types, resulting high variation of efficiency in soil and water conservation. The result of the study highlights that consideration of the role of agro-ecological environment like soil type groupings, climatic, and topographic conditions for successful sustainable land management techniques. A water-balance approach was applied for the study and runoff plots from three sites, each represent different agro-ecological environment in terms of elevation and rainfall were used, The man target was to examine efficiency of different soil and water conservation practices done with their impacts on soil moisture , runoff response and runoff conservation. Common land use types was represented by a unique (cultivated vs. non-agricultural land use types) and slopes (gentle and steep). Seasonal runoff at control plots ranges 214–560 in the highlands, 253–475 mm at midlands and 119–200 mm at lowlands. The runoff conservation efficiency in cultivated land has increased by 32% to 51% due to those sustainable land management works applied, depending on the site conditions. Soil and water conservation have also improved soil moisture content enough to potentially cause water logging, which was absent at the low rainfall sites at the moist subtropical site in a highland region. The runoff in cultivated land (51% and 55%, respectively) has conserved by soil bunds combined with Vetiveria zizanioides grass and short trenches in grassland.

Hydrus 1d model is also a model that can be applied to detect the impact of land use changes on soil physical and hydraulic properties in plot scale. Various studies has been conducted on this model to know the implications of land use and management on hydrology of watersheds In a study by  Bush et al. (2020) to assess the impact of land use on the plot scale overland flow found an output that run off ratios and plot scale overland flow has higher values in the pasture land than in forest area. The study was conducted to compare the plot scale overland flow generation of two separate land use types in central panama. Hydrus 1 d model has been applied to simulate overland flow with different measured soil characteristics and rainfall data were applied as an input for Hydrus 1d model and the model provide an estimation output of plot scale overland flow. The theoretical base for this study is the impact that land use can create on the soil physical and hydraulic properties like Bulk density, Organic content, soil moisture content, hydraulic conductivity, infiltration and overland flow (Biggs et al., 2006; Hanson et al., 2004). The study also revealed that overland flow generated by infiltration excess, Hortonian overland flow (HoF) (Horton, 1933) is the main driver of plot scale pasture land overland flow during high rainfall. The research strongly addresses its objective to answer impact of land use on overland flow but has limitations using wider land use types in addition to forest and grazing land that’s somehow can provide extreme output results.

According to Giri et al, (2018) in their study on *Water security assessment of current and future scenarios through an integrated modeling framework in the Neshanic River Watershed"* The research mainly was conducted to made water security assessment based on the concept of blue versus green water. Blue water is the combination of surface runoff and deep aquifer recharge while green water is the summation of evapotranspiration and soil water content (i.e. mediated by plants). Due to the tight coupling between land use and the partitioning of blue and green water within a watershed, an integrated geospatial modeling framework that links land use and watershed hydrological processes is needed to predict the consequences of future land use change on blue versus green water security. By loosely coupling an agent based probabilistic land use change model with a hydrologic model, the study investigated the consequences of present trends of urban growth to identify potential future hotspots of hydrological change across a watershed in central New Jersey undergoing suburbanization. This study is also general study that can incorporate our study which is the part of land use or watershed management practices implication on water security.

The study also focused on the consequence of the loss of forest land and increasing impervious surface leading was higher blue water but lower green water. While no severe blue water scarcity was observed, an increasing green water scarcity was found in some study area sub-basins. The paper used three types of methodologies to address the research 1) Hydrological modeling framework, 2) Agent-based modeling framework, and 3) Spatial data analysis framework

Finally, the paper concludes getting significant impact of Land use land cover on water security through analyzing water security based on current land use and population and projected land use and population. The research has strengths on its selection of methodology that's integrated GIS methods for processing remote sensing and hydrology data and answer the research question in a precise manner.

# CHAPTER 3

# Materials and Methods

## 3.1. Description of the study area

### 3.1.1 Location and accessibility

The study area is called Aba Gerima watershed and it is located in Region 3/Amhara region, West Gojam zone, Bahir Dar Zuria Woreda specifically in Aba Gerima Gonibat Kebele. It is about 15km far in north east direction from the regional capital Bahir Dar. The head of the watershed at its southern part can be accessed through a fairy weathered road that connect from Zenzelima village with Abune hara Monastry, where the boundary of the watershed touches the road to the north off-ramp at a village called Aba Dama. Aba Gerima watershed is layed on three kebelles namely, Robit _Debre tsion on the North west, Gonibat Abagerima to the north and North west and Laguna Abune Hana to the south and south west, but majority of the watershed is found in Gonibat Abagerima kebele. The watershed covers around 900ha of area located in Tana sub- basin nearby Lake Tana.

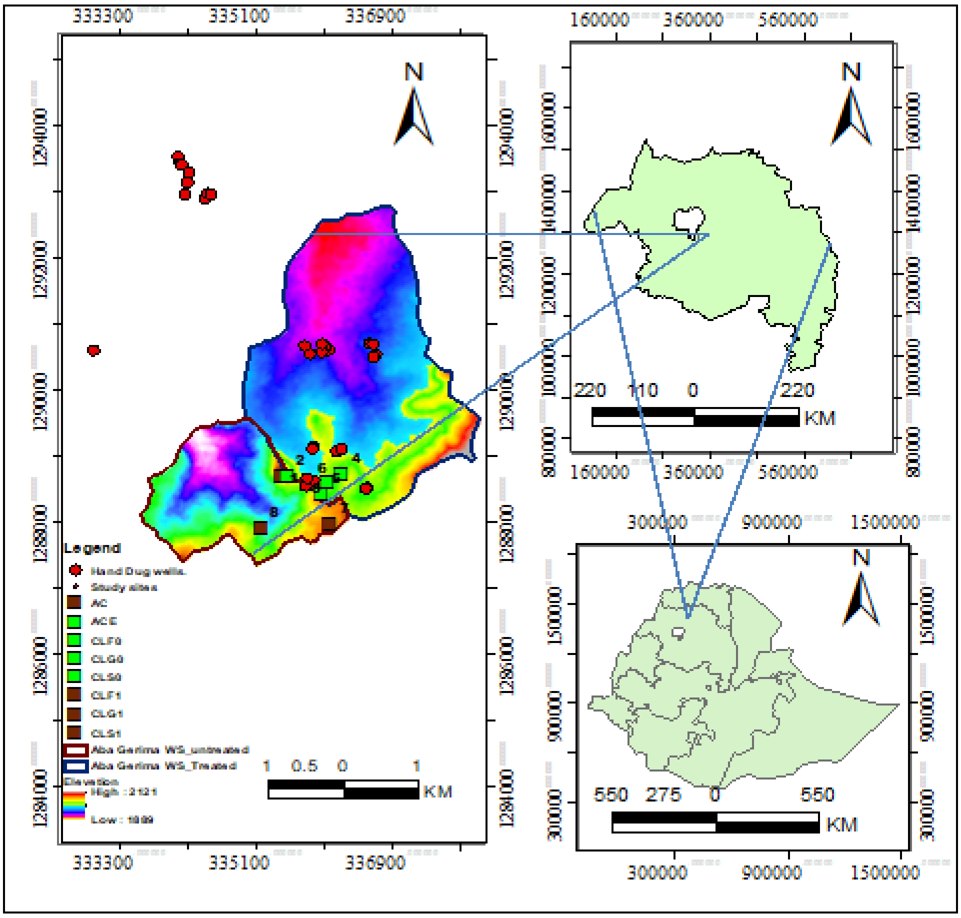


Figure 2. Location of Aba Gerima watershed with study sites & ground water points

### 3.1.2. Climate

The climate in the upper Blue Nile basin is primarily governed by the seasonal migration of the Inter-Tropical Convergence Zone (ITCZ) from the south to the north and back. Rainfall is high in the study watershed. Average annual rainfall amount of the study watershed is1300mm. Most of the precipitation events fall in short-duration and high-intensity Thunderstorms with high level of erosive, causing severe soil erosion in the study watershed. The long-term average temperature in the study watershed is 20 Degree centigrade (http://www.wlrc-eth.org).

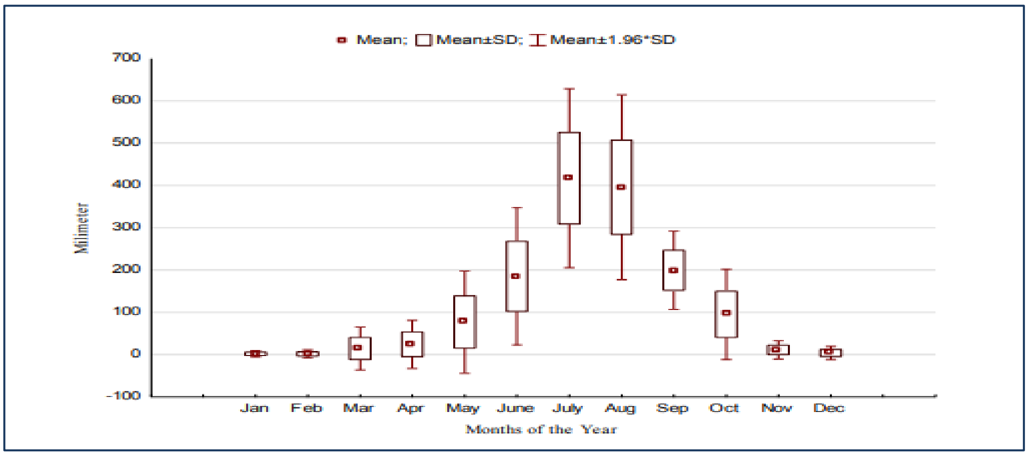


Figure 3. Mean monthly rainfall in Aba Gerima area (within 1996-2015) (Mekuria et al, 2018).

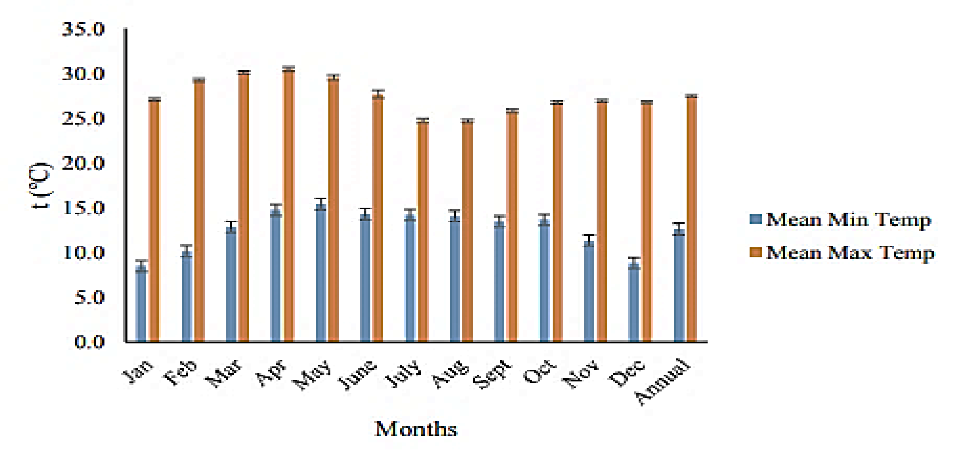


Figure 4. Mean monthly and annual minimum and maximum temperature (within 1996-2015). Bars represent standard errors of means (Mekuria et al, 2018).

### 3.1.3. Soils

According to Conway, (2000) geologically, the upper Blue Nile basin is dominantly underlain by volcanic and Pre-Cambrian basement rocks with small areas of sedimentary rocks. From Betrie et al., (2011), the dominant soil types of the basin are Alisols and Leptosols followed by Nitisoils, Vertisols and Cambisols. Lake tana sub basin consists these major soil types chromic luvisoils, Eutric cambisoils, eutric Leptosoils, Eutric regosoils, Eutric vertosoils, Haplic alisoils,Haplic luvisoils, Haplic Nitisoils,Lithic leptosoils. Gleysols & Nitisols are the type of soils underlain the study area around the experimental points. According to FAO, (1988) soil grouping Gleysols are soil types formed in ground water affected areas with prolonged saturation mostly from unconsolidated parent material. It has poor rooting condition, lack of aeration and poor for soil fauna while Nitisols are deep, more permeable, well drained tropical soils mostly formed in a hilly environment from basic parent material. According to classification Loam and Clay Loam soils are the dominant soil texture of the watershed. High degree of land degradation from intensive cultivation without proper management practices made the soils in the study watersheds to be poor and of low productivity potential. (http://www.wlrc-eth.org).

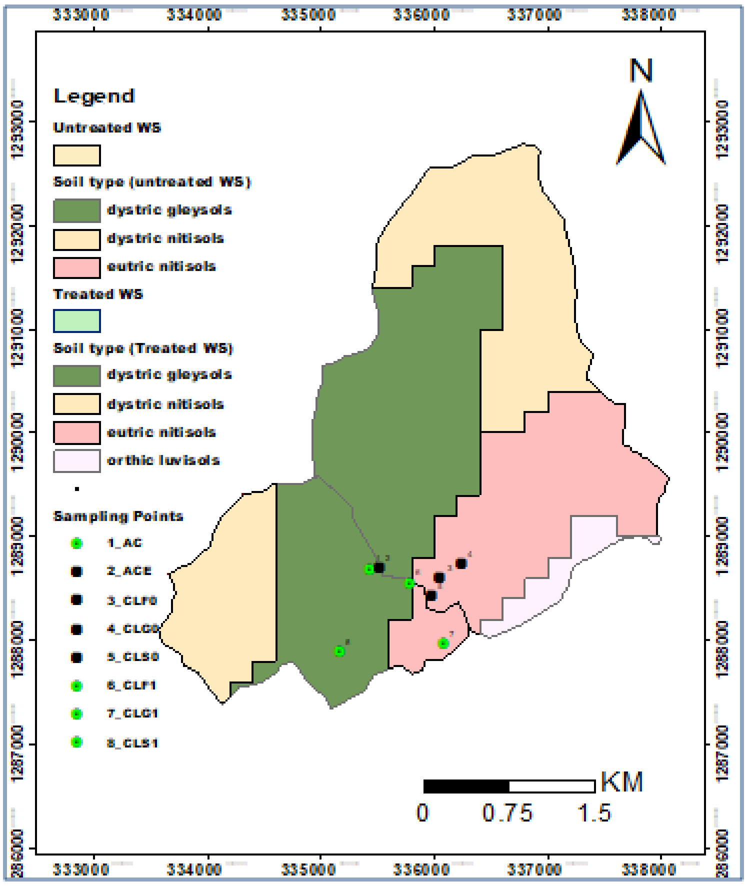


Figure 5. Soil type map of Aba Gerima watershed (FAO, 1988)

### 3.1.4. Land use

According to Berihun et al., (2019) on the study made to examine the trends, driving factors, and implications of LULC for the past 35 years (1982–2017) in three watersheds of different agro ecologies of Upper Blue Nile basin: Guder (highland), Aba Gerima (midland), and Debatie (lowland). Change detection of LULC was made by used by integrating field observations, remote-sensing data (aerial photographs [1: 50,000 scale] and very high resolution [0.5–3.2 m] satellite images), and geographic information systems. The drivers of LULC were explored using key informant interviews and relevant literature reviews. The study revealed that forest land was the dominant LULC class accounting for 32.0% in Aba Gerima watershed in 1982. From 1982 to 2016/2017, forest land, bush land, and grazing land respectively decreased by, 65%, 49%, and 63% in Aba Gerima. During the same period, cultivated land increased by approximately 129%, in Aba Gerima. The expansion of cultivated land combined with population growth linked to the increase of gully erosion and surface runoff potential in Aba Gerima watershed. The following figure (Figure 6 ) described the land cover map of Aba Gerima in 2021 obtained from (WLRC, 2021)

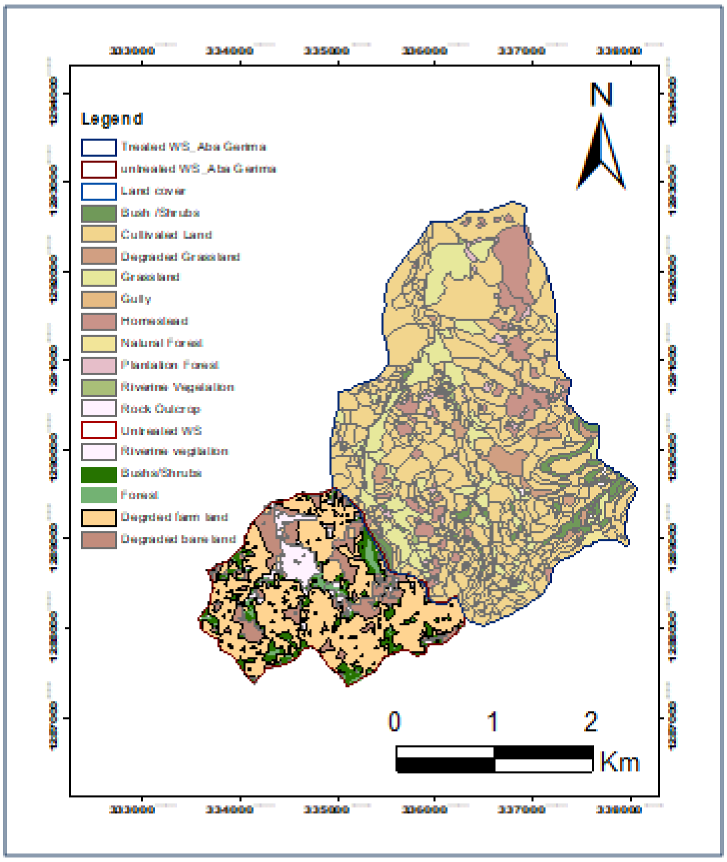


Figure 6. Land cover map of Aba Gerima watershed (WLRC, 2020)

### 3.1.5. Geology

Geologically, Ethiopia's topography is formed with five geological formations created in different periods from Precambrian till recent. In most places of the country, younger volcanic and sedimentary formations overlay the older Precambrian Metamorphic and volcanic intrusions except in peripheral lowlands. Thick sedimentary sequences, deposited by Mesozoic marine transgression regression dominantly limestone and sandstone, most of which have been either eroded or overlaid by volcanic sequences of younger rocks. Tertiary and quaternary lava flows covered more than half of the country with thickness reaching up to 3000 m (Kazmin, 1979). These rocks were affected by several structural episodes in the geological past. Especially, the rift formation defined the present-day geomorphology. When we see the Geology of Ethiopian highlands, a voluminous fissure-fed basaltic lava flows of materials began to form explode flood basalt plateau, piling layers upon layers 30 million years ago. The basaltic flow was mostly of tholeiitic, with thin layer of alkali basalts and minor amounts of felsic (high-silica) volcanic rocks, such as rhyolite. In the first stages of the flood basalt episode, large caldera-forming explosive eruptions had been also occurred. Igneous rocks comprise the Mio-Pliocene 'Trap Series' and the Quaternary 'Aden Series' (Gani, Gani, & Abdelsalam, 2007; Kazmin, 1972). The Trap series (mainly basalts) extruded from fissures and centers of flood lavas and built up a 500– 1500 m thick volcanic pile (Mohr, 1964; Mohr & Zanettin, 1988). As a part of North western Ethiopian plateau and lake Tana sub basin, Aba Gerima watershed is also Geologically located in this thick Basaltic succession of western high land plateau. The Geomorphology of Aba Gerima watershed ranges from flat lands covered by thick, highly weathered basaltic regolith in Gombat to fresh, hard and massive basaltic plugs near Laguna Georgis which is above 2200m amsl.

### 3.1.6. Topography

In Aba Gerima watershed about 55% of the land is less than 8% which is near flat and gently sloping. This confirms that the majority of the land is favorable for crop cultivation either with rainfed agriculture or by irrigation. Only about 20% of the land is grouped under steep and very steep slope with inappropriate slope and soil type due to its hilly or steep nature. However, nearly 30% of the watershed needs serious attention to use the land for cultivation since farming activities in these places can aggravate soil erosion and degradation.

The watershed has highly heterogeneous landscape as the elevation variation is very gradual within short lateral distance. Like many other areas that surround Lake Tana, Aba Gerima watershed has diverse relief pattern that incorporate flat land, very small to high hills and somehow mountainous at its southern edge in Tenta Laguna kebelle. Since the slope changes steadily with some lateral distance sharp falling terrain, high mountainous and valley features haven't seen in the watershed. However, hills and depressions with some flat land areas are very common; namely, Laguna, Yijaj, Kuraze, Enkoy got and Kecha hills are major hills in the watershed. The altitude of the watershed ranges from 2118m at Eastern edge of Laguna Giorgis to 1893m a.s.l at called River Yidemu that crosses Gombat Kebelle which is the outlet of the watershed. The elevation difference between highest and lowest points in the watershed (1893 and 2120m) is about 227m. (http://www.wlrc-eth.org) This nature of the watershed made its geomorphology to be changed gradually along horizontal distance and forms rolling and gentle slope landscape.

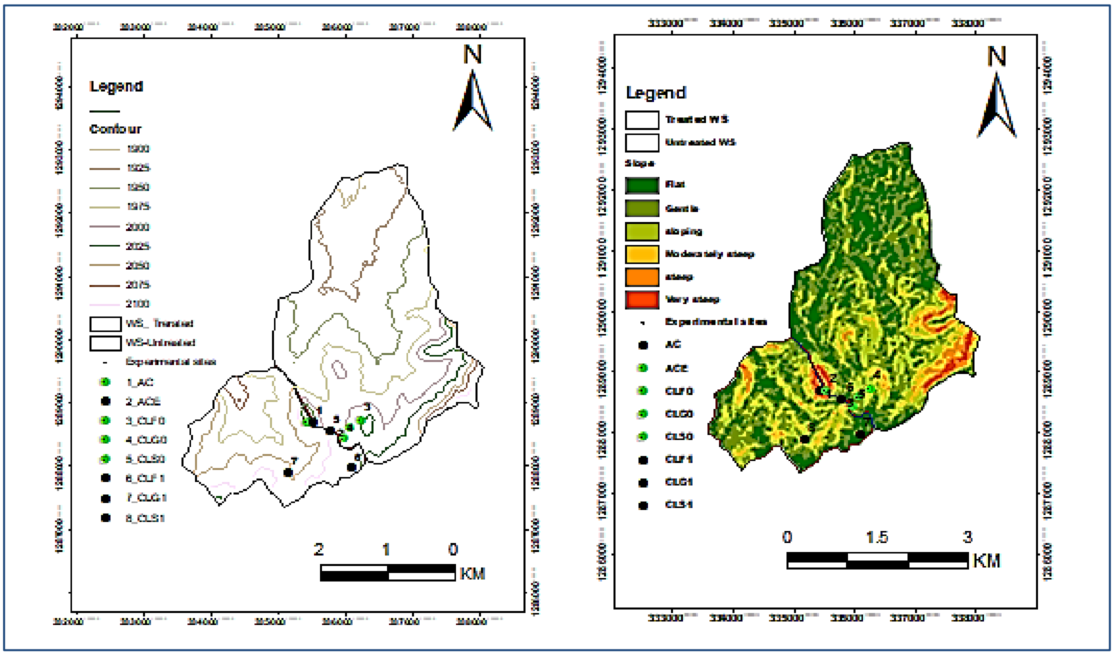


Figure 7. Contour and slope map of Aba Gerima land scape

The slope of the watershed can be also classified in to 6 generalized categories or classes of slope conditions as in the below table; Table 1.

| SN | Slope | Slope % | Area Coverage (ha) | Percent cover (%) |
|---|---|---|---|---|
| 1 | Flat or almost flat | 0-3 | 97.7 | 10.9 |
| 2 | Gently sloping | 3-8 | 404.9 | 45.0 |
| 3 | Sloping | 8-15 | 273.7 | 30.4 |
| 4 | Moderately steep | 15-30 | 103.1 | 11.4 |
| 5 | Steep | 30-50 | 20.0 | 2.2 |
| 6 | Very steep | >50 | 1.0 | 0.1 |
| Total | | | 900.3 | 100 |

Table 1. Slope percent range

### 3.1.7. Drainage patterns

Aba Gerima is a small watershed with diverse landscape features ranges from flat land at its lowest places like Aba Gerima and Zenbet localities of Gombat kebelle to hills and mountains at Laguna and some parts of Robit_Debretsion kebelle. It represents peculiar landscape of Bahrdar zuria woreda that looks like plain but has rolling up and down scenery in detailed view. Since the watershed is a part of the Lake Tana sub basin located nearby Lake Tana all streams from the surroundings of Aba Gerima flow towards Lake Tana. According to the document WLRC, (2010). The drainage of the area mainly follows dendritic river pattern and most of the streams in the watershed raised from the highlands of Aba Gerima. One major and two small depressions cross the watershed, which both are connected to the larger Gelda watershed that incorporates Gelda stream and flows to Lake Tana. The first and the larger depression go from south towards west holding River Wotet Minch and River Yidemo. The second rises from Enkoy Got to Tach Kecha following Andayitetash Valley, and the other one rises from Yijaji hill towards the Tach Kecha village dissected by Dokima Wonz. The main river that flows out of Aba Gerima to join Gelda river, then Lake Tana is Yidemo. Yidemo is a river that rises from the highlands of Laguna in Aba Gerima. It's a perennial river that has very low yield during dry season of the year. The dendritic drainage pattern of Aba Gerima (Figure 4) and plate i shows stream discharge station on Yidamo river in dry season (March,2021).

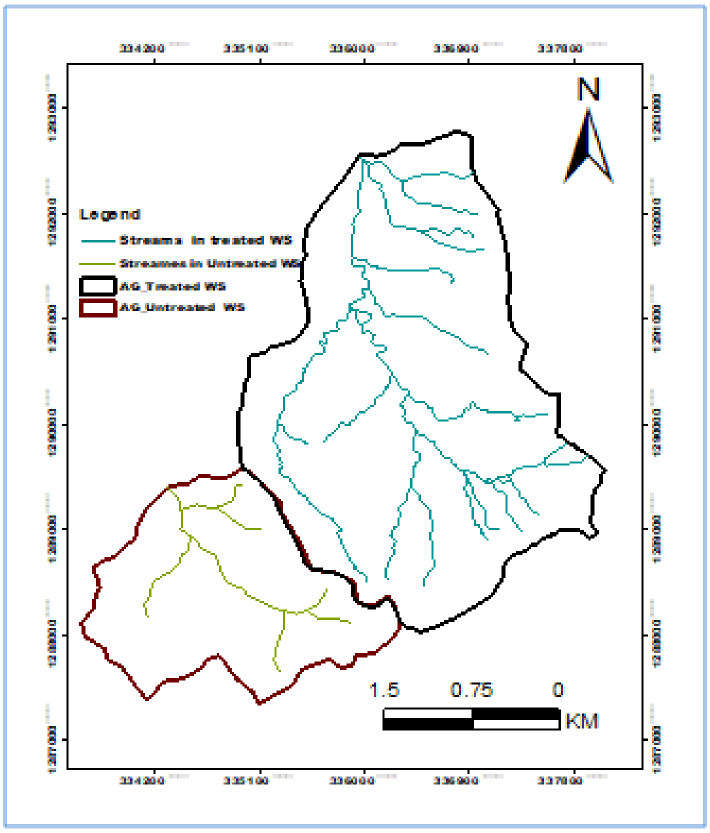


Figure 8. River pattern map of Aba Gerima watershed

## 3.2 Data Sources

The following input data was collected for Hydrus 1D modeling and analysis of the study sites. In addition to this some remote sensing data was also collected and analyzed for study area description.

**Topographic data:** Elevation, slope gradient and geomorphic parameters was derived from Digital Elevation Model (DEM) of SRTMGL1 (NASA Shuttle Radar Topography Mission Global 1 arc second (~30 m) V003) obtained from the web, USGS Earth explorer https://earthexplorer.usgs.gov/ . The collected data was further analyzed with ArcMap 10.3.1 for study area description and characterization.

**Soil map:** In addition to this, soil type map obtained from Ministry of Agriculture was applied in study area description. In the study area description soil type map obtained from Ministry of Agriculture was used.

**Meteorological data:** Mean daily precipitation; daily max and daily min air temperature were collected from stations in Aba Gerima watershed (WLRC) for our study period. In addition to these data, wind speed, solar radiation, and relative humidity of long-term record has been collected from different stations near our study area to understand areal atmospheric conditions and fill missing data for our study area.

**Land management data:** In this study spatially, Land management data has been collected using field observation, different unpublished local administrative reports and explicit map of terrace systems and contour tillage has been produced using Very High-Resolution Google Earth images. The support practice factor, $P_{USLE}$, is defined as the ratio of soil loss with a specific support practice to the corresponding loss with up-and-down slope culture. Support practices include contour tillage, strip-cropping on contour, and terrace systems.

**Ground water level data:** This data was used to determine whether ground water could reach to the sampling soil profile or not & select the assumption for the bottom boundary condition 'Free Drainage' in the model input. This assumption requires the groundwater table in the area to be deep enough to not affect redistribution of water in the soil profile under sampling. Dry and wet season static water level of hand dug wells near the vicinity of the study area were surveyed to ensure this assumption. The location and distribution of surveyed hand dug wells was mapped in Figure 2 and detail data was documented as Appendix 5.

**In-situ soil physical property and moisture data**: Most important soil parameters that are required for the model were found from in situ measured and recorded data in WLRC: hydrologic soil group, depth, and texture and Bulk density, with available water capacity, saturated hydraulic conductivity, factor values at each layer basis. Quality-controlled in-situ volumetric soil moisture measurements ($m^3m^{-3}$) from Aba Gerima watershed collected from August 2017 to May 2019 at different soil layers (10cm, 20cm, 30cm, and 40cm) was obtained from WLRC.

| S/N | Data type | Data Source | Purpose |
|---|---|---|---|
| 1 | Soil Physical and Hydrological properties | WLRC, Oxford | Modeling water balance components |
| 2 | Crop Growth data (soil depth) | Farmers Training center of Laguna and Gombat kebeles | Modeling water balance components |
| 3 | Meteorological Data | WLRC, ENMA | Modeling water balance components |
| 4 | Digital elevation Model (DEM) | USGS Earth explorer (https://earthexplorer.usgs.gov/) | Study area description |
| 5 | Soil type Map | FDRE Ministry of Agriculture | Study area description |
| 6 | Ground water level and wells location | Field survey in Aba Gerima | Ground water points (i.e; SWL) assessment to ensure the assumption that ground water doesn't interact with soil moisture at the study depth (~400mm) in Hydrus 1D. |
| 7 | Aba Gerima shape file & Land cover map. | WLRC, Oxford | Detailed high resolution study area description. |

Table 2. Data type and sources

## 3.3. Research Methods

The research method followed to conduct this research was organized accordingly to address the objectives of the research. The first methodology which is analysis of in situ measured soil physical and hydrological properties was done to estimate the relation between soil physical, hydrological properties and the impact that watershed management practices can have on those properties. The main focus of this study was Hydrus 1D modeling to simulate water balance components using water flow and root water uptake models as the main methodology. The output of the model that estimated water balance components in the study sites was further in comparison to determine the water availability of the study sites under watershed management with the controlled ones. Likewise, most of the small watersheds located in sub-Saharan countries, there’s also high Scarcity of appropriate baseline land management, hydrological and other data that provide enough information about conditions in Aba Gerima watershed before 2012. Therefore, the selected methodology addressed our study objective of water availability implications of watershed management practices in Aba Gerima with this very limited baseline data. Hydrus 1d model simulation of water balance components in the 8 study sites has been done to estimate in flow and out flow components of water balance. The inflow components include infiltration, soil water content, Recharge and dry time surface run off. However, the out flow is Actual Evaporation, Transpiration (Actual root water uptake) and wet time surface run off. Based on simulation results of those water balance components, the sites under watershed management practices has to be compared with controlled sites to know which group of sites has better water availability described in terms of infiltration, surface run off (surface flux) in dry time, soil water storage and recharge (bottom flux). However, actual Evaporation and transpiration (root water uptake) indicates that the water that leaves the system in the study period. So, the sites that have higher amount of actual evaporation and root water uptake has lower available water since both groups of sites are assumed to be under the same climatic conditions. Hydrus 1D version 4.xx was the software used for modeling and Microsoft excel was applied to process the raw output in an organized meaningful basis. Hydrus 1D is the program that solves the Richards' equation numerically for water flow. The Flow equation includes a sink term to account for water that plant roots uptake.

Generally, One directional water flow of uniform single layered soil profiles, 1D water flow of non-uniform multi layered soil profiles was also be analyzed in Hydrus 1D model. The input data for calculation of 1D water flow and root water uptake was collected and inserted to obtain simulation results.

This methodology was selected since there was available Meteorological, in situ soil, crop growth, root depth, Ground water level data for the study as listed in the table (Table 2) and the program Hydrus 1D is available on the web PC progress (https://www.pcprogress.com/en/Default.aspx?Downloads) freely without charge.

### 3.3.1. Scenario Design

One dimensional water flow model with root water uptake was used to simulate soil water balance components under different land management systems under controlled and watershed management practices. The Soil type and characteristics was studied and recorded for each study site where each pair of sites was under the same slope, land use type, climate and sampling depth. However, each of the controlled sites varied with its respective WSM site with only in land management style (WSM) condition. The following table (Table 3) describes the conditions of all the 8 sites under the study.

After simulating water balance components, comparison of the Hydrus 1D post processing output for each of the study site under watershed management practices versus the respective controlled sites to determine which group of sites has had better availability of water. The comparison clearly used to evaluate water availability differences between them and in the meantime the impact of watershed management practices on water availability Microsoft Excel 2010 was applied to further process and made the comparison of the outputs (i.e. soil water balance components) for each site which are under watershed management practices versus their corresponding sites in controlled system. The main objective of this comparison was to evaluate water availability differences between the two groups of sites, in the meantime the impact of watershed management practices on water availability.

| Site Code | Description | Slope | Soil Type | Crop type |
|---|---|---|---|---|
| AC | Degraded land (control) | | Dystric Gleysols | Area closure with a history of open communal grazing |
| ACE | Degraded land, but currently under closure (under WSM practices) | | Dystric Gleysols | with a history of open communal grazing |
| CLF0 | Cultivated land under WSM practices. | Flat | Eutric Nitisols | Finger millet |
| CLG0 | Cultivated land under WSM practices. | Gentle | Eutric Nitisols | Maize |
| CLS0 | Cultivated land under WSM practices. | Steep | Eutric Nitisols | Maize |
| CLF1 | Cultivated land (control) | Flat | Dystric Gleysols | Finger Millet |
| CLG1 | Cultivated land (control) | Gentle | Eutric Nitisols | Maize |
| CLS1 | Cultivated land (control) | Steep | Dystric Gleysols | Maize |

Table 3. Sampling sites Land use, management, soil type and Slope description

### 3.3.2. Model Setup and Input Parameters

The aim of the hydrological modeling here was to simulate water flow and root water uptake in a 40 -cm deep different layered soil profile and to evaluate flow across the bottom boundary of the profile (i.e., groundwater recharge). The soil profile is initially at a uniform pressure head equal to -40 cm. The boundary condition for the soil surface is an ‘Atmospheric Boundary Condition with Surface Runoff’. The bottom boundary condition is ‘Free Drainage’. In the area closures Roots are uniformly distributed from the soil surface down to a depth of 20 cm. in the cultivated lands maize and finger millet were crop types that have been cultivated with different root growth time series data. A 365-day time series of meteorological data from the WLRC, has provided, which allows us to calculate daily values of potential evapotranspiration. The HYDRUS-1D model is thus used to calculate actual plant water uptake (i.e., actual transpiration) and to estimate deep drainage below the root zone, which eventually recharges the underlying aquifer.

Inverse modeling method has been applied to estimate soil hydraulic parameters from Soil textural properties (sand, Silt, clay ratio, bulk density, soil organic matter content, Ks). SM data was also collected from each site at 100,200,300 and 400mm depths and volumetric water content was estimated at each depth to represent depth ranges. Hydrus 1D model was applied to simulate water flow in a 40-cm deep, multi-layered soil profile depending on sites number of soil layer. Time-variable atmospheric boundary conditions (daily values of precipitation and evaporation) are specified first. Finally, soil water balance components for each site which are under watershed management practices versus their corresponding sites in controlled system were compared to evaluate water availability differences between them. In the meantime, the impact of watershed management practices on water availability has been discussed with respect to the findings of the modeling.

### Initial Conditions and Boundary Conditions

Initial conditions in this study were:

$h(z, 0) = h_0(z)$…………………………………………………………... (3.1)

Where, $h_0$ is the initial pressure head in the soil profile (cm). The surface layer was assumed to be the initial boundary of the recharge from precipitation. There was no additional water flow in to the study sites rather than precipitated water which was the only water input in the model during the study period. The upper boundary conditions were the atmospheric conditions at the soil surface with surface runoff. The lower boundary condition was free drainage below the root zone for all of the eight cases in the study. This assumption was done since the water table was far below the bottom boundary of the soil column, and there was no groundwater recharge to the root growth zone. Ground water survey conducted in the area ensures this assumption and the static water level of all wells was below the study depth (400mm) in both dry & wet seasons. Precipitation and evaporation were the major processes that define the upper boundary conditions. We estimated the potential transpiration and evaporation using the Hargreaves equation (Hargreaves et al., 1985) and the daily values from the weather measurements (maximum temperature, minimum temperature, and average Precipitation) obtained from the meteorological station in Aba Gerima watershed. The following equation (equation 3.2) can show boundary conditions as:

$-k((\partial \mathrm{h}\ \partial \mathrm{z}\ +\ 1) = 0, z = L$……………………………………………………. (3.2)

Where, L is the depth coordinate of the soil surface and is equal to 40 cm at the maximum depth at which the soil dry bulk density and particle size distribution were measured and analyzed. Using this data,

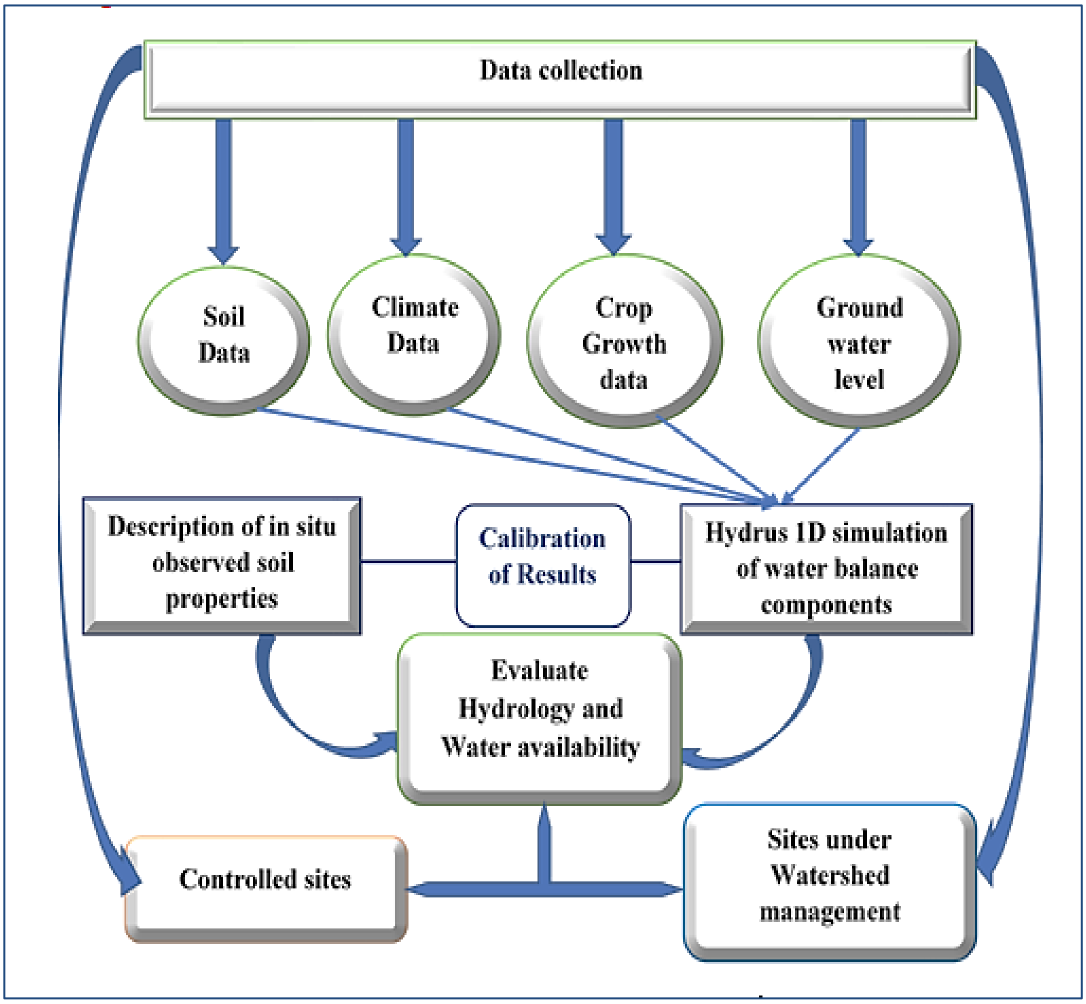


Figure 9. Logical framework of the study

### Root Water Absorption

We adopted Feddes' function (Fedes et al., 1978) to simulate the water absorption process of the black locust root system:

$S(z, t) = \ b'(z)\alpha(h)Tp$……………………………………………………….. (3.3)

Where b '(z) is the relative root distribution function (dimensionless) and α(h) is a dimensionless water stress function. $T_p$ is the potential transpiration rate. To optimize the root water absorption, α(h) was set to 1 during the calibration period. The measured root data were used mainly in the b '(z) function. The b'(z) function (Hoffman et al.,1983) is as follows:

Where Lr is the root length (cm)

$$b'(z) = \begin{cases} \frac{1.6667}{Lr} & z < 0.2Lr \\ \frac{2.0833}{Lr}\left(1 - \frac{z}{Lr}\right) & 0.2Lr \leq z \leq Lr \\ 0 & z > Lr \end{cases} \dots\dots\dots\dots\dots\dots (3.4)$$

### Spatial and Temporal Discretization

The 0–40 cm soil profile was divided into multiple layers according to the soil properties. The soil profile was divided into 40 units at equal intervals of 1 cm. correspondingly; the soil profile has 41 nodes and 4 observation points (10 cm, 20 cm, 30 cm, 40 cm). The simulated period ranges from 23 August, 2017 to 22 August 2018, i.e., 365 days. The interval of the time discretization was adjusted bit by bit accordingly with the amount of iterations of the convergence. If the number of iterations needed to reach convergence at any time in a specific period exceeded the preset maximum value (generally range 10–50), then the iteration was terminated, and the period length was changed to Δt/4 to repeat the iteration. Each quarter define one season in our study and 4 print times were set throughout 365 days study period in this thesis. The initial time interval was set to 0.0001 d, the maximum time step was set to 5d.

## 3.3.3. Calibration and Validation

We divided the soil profiles into multiple layers based on the soil physical properties at each site, and the saturated water contents θs were calculated using the pF soil water characteristic curve measured for the soil samples in the laboratory. We estimated θr , Ks , and the empirical shape parameters n and α using the Rosetta based on the neural network embedded in HYDRUS-1D from the data for the mechanical soil composition, and soil bulk density. The initial values of the parameters for each layer were estimated using the Neural Network Prediction embedded in the model, and then, the parameters were fitted by fitting the measured values for all layers in all of the study sites. The van Genuchten-Mualem Equation parameters were determined from those observed values.

| Site | Layer | Water flow parameters | | | | | |
|---|---|---|---|---|---|---|---|
| | | Qr | Qs | Alpha | N | Ks | I |
| AC | 1 | 0.0487 | 0.04813 | 0.0136 | 1.4602 | 176.37 | 0.5 |
| AC | 2 | 0.069 | 0.522 | 0.0184 | 1.4166 | 124.46 | 0.5 |
| AC | 3 | 0.0922 | 0.5647 | 0.0103 | 1.4822 | 125.47 | 0.5 |
| AC | 4 | 0.1099 | 0.06282 | 0.0211 | 1.3282 | 149.86 | 0.5 |
| ACE | 1 | 0.0732 | 0.4476 | 0.0085 | 1.5453 | 23.11 | 0.5 |
| ACE | 2 | 0.0919 | 0.5322 | 0.0108 | 1.4728 | 64.2 | 0.5 |
| CLF0 | 1 | 0 | 0.55 | 0.0189 | 1.2037 | 32 | 0.5 |
| CLF0 | 2 | 0 | 0.5124 | 0.0207 | 1.1984 | 36.2 | 0.5 |
| CLG0 | 1 | 0.0873 | 0.4844 | 0.0097 | 1.4954 | 25.9 | 0.5 |
| CLG0 | 2 | 0.1075 | 0.5932 | 0.0204 | 1.3279 | 91.56 | 0.5 |
| CLG0 | 3 | 0.0988 | 0.5675 | 0.0174 | 1.3843 | 88.63 | 0.5 |
| CLS0 | 1 | 0.0785 | 0.4767 | 0.0092 | 1.5254 | 34.42 | 0.5 |
| CLS0 | 2 | 0.099 | 0.5113 | 0.0174 | 1.346 | 30.08 | 0.5 |
| CLS1 | 1 | 0 | 0.5124 | 0.0207 | 1.1984 | 52.9 | 0.5 |
| CLS1 | 2 | 0 | 0.5077 | 0.0218 | 1.248 | 52.92 | 0.5 |
| CLS1 | 3 | 0 | 0.5077 | 0.0218 | 1.248 | 12.8 | 0.5 |
| CLS1 | 4 | 0 | 0.5077 | 0.0218 | 1.248 | 12.8 | 0.5 |
| CLG 1 | 1 | 0.1057 | 0.5768 | 0.0207 | 1.3323 | 77.19 | 0.5 |
| CLG 1 | 2 | 0.087 | 0.5155 | 0.0147 | 1.4265 | 46.89 | 0.5 |
| CLG 1 | 3 | 0.0841 | 0.5337 | 0.0142 | 1.4375 | 74.99 | 0.5 |
| CLS1 | 1 | 0.0684 | 0.5125 | 0.0184 | 1.4212 | 112.82 | 0.5 |
| CLS1 | 2 | 0.0628 | 0.4484 | 0.0086 | 1.5512 | 41.87 | 0.5 |
| CLS1 | 3 | 0.569 | 0.4739 | 0.0201 | 1.4396 | 105.39 | 0.5 |

Table 4. Water flow parameters estimated by Rosetta 1v

**Assessment of the Goodness of Fit**

We compared observed field measurements of 365 days daily soil moisture data with the results of the HYDRUS-1D simulations using the ME, mean absolute error (MAE), and root mean square error (RMSE). Hydrus 1D model predicted soil moisture content of each site for 365 days study period for each of the given soil layers. In the assessment of the goodness of fit this simulated Soil moisture data is compared with field observed and recorded results to check the prediction efficiency of the model. Besides to this, the output results obtained from Hydrus 1D simulation has been evaluated with respect to findings of other similar researches conducted around that area to check whether the results or the findings of this study are pretty nice to simulate ground conditions.

Hydrus 1d inverse solutions calibrated results with the best fitted soil moisture content recorded data and provide results of $R^2$, ME, mean absolute error (MAE), and root mean square error (RMSE) in Inverse solution output table.

# Chapter 4

# Results and Discussion

## 4.1. Results

### 4.1.1. Description of observed soil physical and Hydraulic properties

Based on the in situ measured soil physical and hydrological properties of the study sites, the hydraulic property of soil profile largely depends up on physical characteristics of soil layers in the soil profile. Soil physical properties like Sand: Silt: Clay ratio and bulk density can also be largely affected by various factors like Vegetation, Slope, topography, climate and different management activities done on the study area. In our study sites, soil properties like textural composition, OC, BD, soil moisture content was measured for 400 mm soil profile of all the 8 sites at 100 mm depth interval (i.e., 100, 200, 300, 400 mm). Based on this, the thickness of soil profile under analysis is 400 mm. Most of the soil profile in those measured soil layers is dominated by clay, clay loam and loam soil textural set up in all of the study sites. Field observation assessments in the watershed indicated that, the thickness of soft surface material may exceed 2m in the healthy undegraded parts of Aba Gerima watershed. From the analyzed results of the soil sample test, saturated hydraulic conductivity of soil layers decreases downwards in sites under watershed management practices than in controlled sites. In addition to this, based on Rosetta 1v determinations of soil hydrology from its physical property, soil bulk density is the sensitive parameter to determine soil hydraulic conductivity and soil moisture content. So, the mean soil water content of each site can be described with respect to bulk density and hydraulic conductivity as in the following tables. Soil Hydraulic conductivity increases with decreasing soil bulk density which is visible in this study towards the bottom layer ( Table 5 & 6).

| soil layer | layer depth | Mean soil BD (g/cm3) | |
|---|---|---|---|
| | | Under WSM practices | Controlled |
| 1 | 0-10 | 1.169 | 0.855 |
| 2 | 20-30 | 1.112 | 1.095 |
| 3 | 20-30 | 1.102 | 1.091 |
| 4 | 30-40 | 1.036 | 1.0580118 |

Table 5. Observed Bulk densities of sites under controlled situation versus under watershed management practices in various soil layers.

| Site | Water flow parameters (mean) | | | | |
|---|---|---|---|---|---|
| | Qr | Qs | Alpha | N | Ks |
| Under watershed management practices | 0.073538 | 0.45176 | 0.015108 | 1.39895 | 77.09692 |
| Controlled | 0.0977 | 0.50963 | 0.01828 | 1.35507 | 59.057 |

Table 6. Average water flow parameters in sites under watershed management practices and controlled conditions

Where, Qr is Residual soil water content, qr, Qs is Saturated soil water content, Alpha-Parameter a in the soil water retention function [L-1], n is Parameter n in the soil water retention function, Ks- Saturated hydraulic conductivity, Ks [LT-1], L, Tortuosity parameter in the conductivity function [-]

| Site | Mean water content($m^3/m^3$) | | | |
|---|---|---|---|---|
| | $\theta_{100}$ | $\theta_{200}$ | $\theta_{300}$ | $\theta_{400}$ |
| AC | 0.172815 | 0.122967 | 0.092672 | 0.028551 |
| ACE | 0.110731 | 0.192488 | 0.255897 | 0.260572 |
| CLF0 | 0.109054 | 0.178076 | 0.325563 | 0.325023 |
| CLG0 | 0.200673 | 0.238417 | 0.323173 | 0.43662 |
| CLS0 | 0.104518 | 0.116972 | 0.304429 | 0.336768 |
| CLF1 | 0.118646 | 0.154118 | 0.317403 | 0.525972 |
| CLG1 | 0.104665 | 0.155301 | 0.34566 | 0.412575 |
| CLS1 | 0.137072 | 0.306572 | 0.405841 | 0.625153 |

Table 7. Mean measured soil water content of 8 sites at the four sampling depths

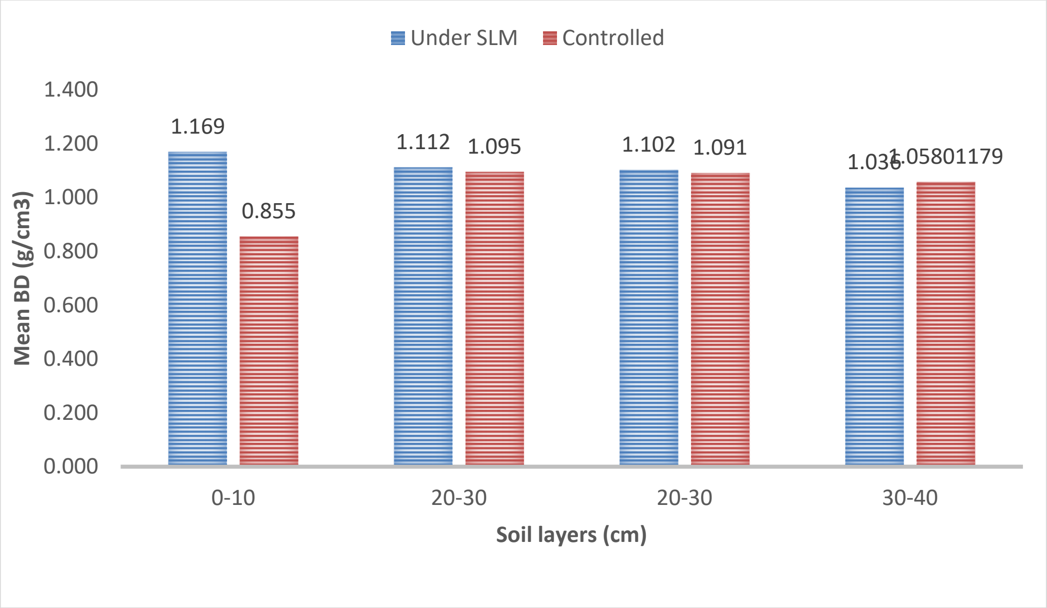


Figure 10. Mean soil Bulk density under WSM and controlled sites

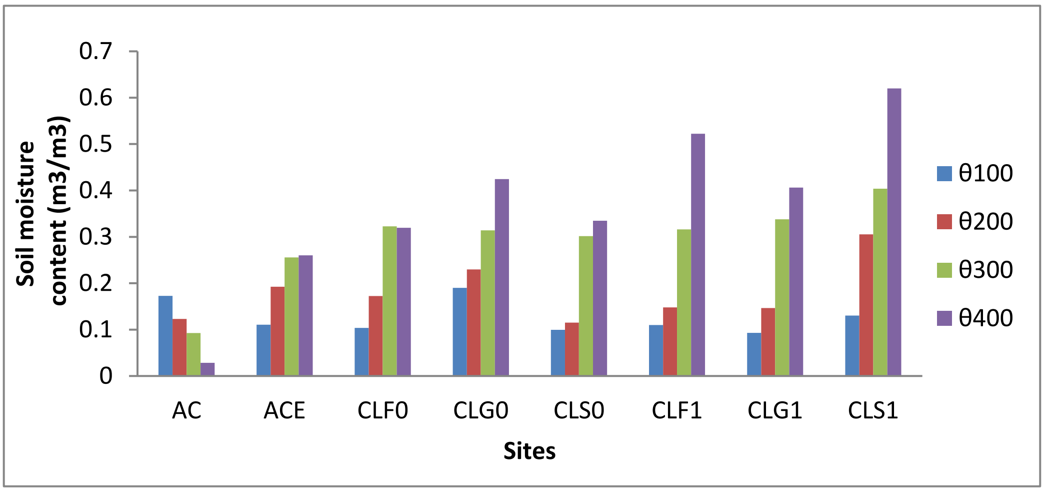


Figure 11. Mean measured SWC of the 8 study sites at the four sampling depths (mm)

When we compare Mean soil water storage of all of cultivated lands under watershed management practices with that of controlled ones with the same slope and crop type (AC and ACE, CLF0 and CLF1, CLG0 and CLG1, CLS0 and CLS1) there is a difference in SWC (Figure10,11/Table 7). The Figure illustrates, mean soil water content increases from surface downwards to 40cm depth in all sites except site 1 which is an area enclosure. The impact of watershed management practices manifested by soil thickness, slope, bulk density organic content and soil texture which are the basic components of soil physical property to control water flow conditions (i.e. velocity). The mean soil water content of the sites under controlled environment mostly increases radically since the soil layer is thin. Besides to this, the impervious layer of basaltic underlying rock surface is very near to the surface and the final sampling depth 40cm. So, Soil water content increased near the boundary of the impervious underlying rock surface and the overlaid soil material. However, in the case of sites under watershed management practices, it’s observed that thicker soil profile with downward decreasing hydraulic conductivity towards the last sampling depth 40cm of the soil profile. This makes the water to flow with faster velocities downwards and feed the bottom flux zone below the root zone than to stay in the upper most soil as SWS. It might need some time to the upper soil layers to be saturated since the soil layers become saturated starting from the bottom upwards due to higher hydraulic conductivity of bottom layers. Unfortunately, this is highly dependent on the thickness of soil layer and the position depth of the underlying basaltic bed rock surface. In our case, this scenario is observed in the condition of cultivated land with gentle slope site which is under watershed management practices but has lower available soil moisture than the corresponding cultivated land with gentle slope but not under the watershed management practices (controlled). However, The CLG 0 has higher in surface and bottom flux values from that of CLG 1.

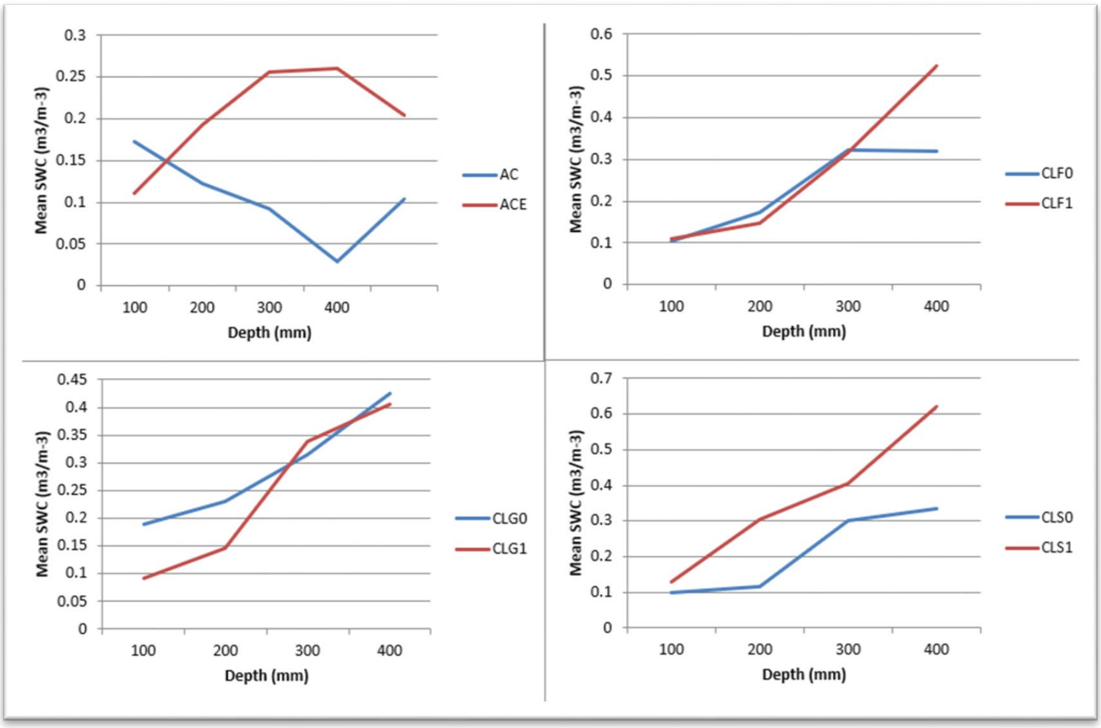


Figure 12. Mean SM with respect to sampling depth in each of respective sites

### 4.1.2. Hydrus 1D simulation of water balance components

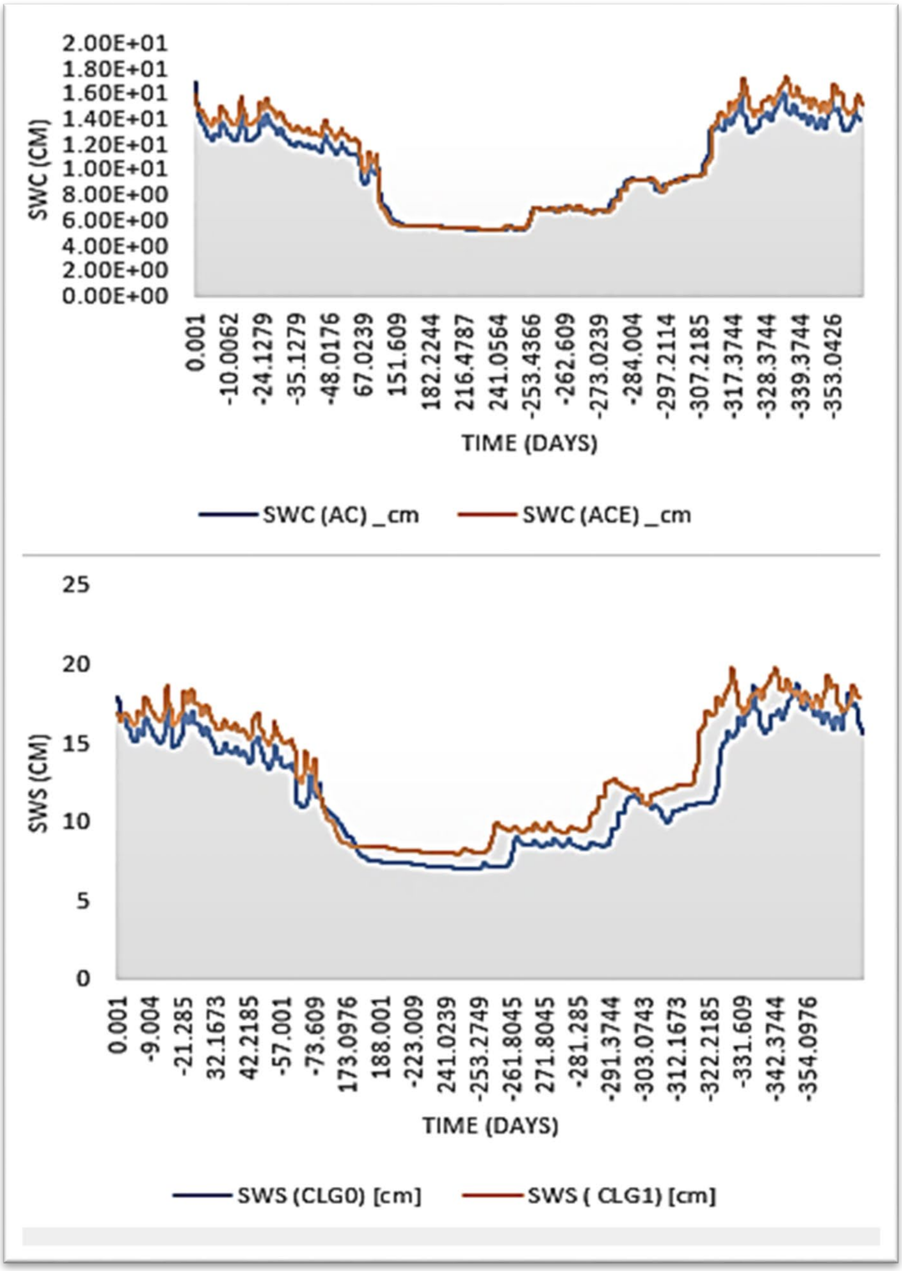
One directional water flow model was simulated for Water balance components in the study period of 365 days from the date 8/23/2017 to 8/22/2018 with Hydrus 1D model for each of the 8 selected sites under watershed management practices and controlled situations. Based on this surface flux, infiltration, soil water storage, Bottom flux, Root water uptake and Evaporation has been examined in terms of water availability of each of the study sites. As its been known Hydrus 1D model simulates only 1D water flow and the results represent only the soil water properties of the study sites.

| Site | Mean Actual Surface flux (cm/day) | Annual Cumulative Infiltration (cm) | Mean Actual Root water uptake (cm/day) | Cumulative Evaporation (cm) | Mean SWS (cm) | Mean Bottom flux (cm/day) |
|---|---|---|---|---|---|---|
| AC | 0.47 | 98.32 | 0.02 | 4.7 | 10.03 | 0.41 |
| ACE | 0.46 | 98.32 | 0.022 | 3.3 | 10.6 | 0.38 |
| CLF0 | 0.4526 | 115.05 | 0.0021 | 31.968 | 15.38 | 0.33 |
| CLG0 | 0.4244 | 115.03 | 0.0044 | 32.27 | 12.057 | 0.328 |
| CLS0 | 0.443 | 115.02 | 0.0019 | 29.424 | 11.35 | 0.35 |
| CLF1 | 0.4537 | 115.23 | 0.0045 | 32.667 | 14.23 | 0.325 |
| CLG1 | 0.4314 | 115.23 | 0.0046 | 32.905 | 13.239 | 0.322 |
| CLS1 | 0.424 | 115.03 | 0.0046 | 32.137 | 10.37 | 0.33 |

Table 8. Summarized Hydrus 1D simulation Results of water balance components in the 8 sites

### Soil water storage

From simulation results the mean soil water storage of the AC which is area closure was 10.037 cm with pick value 16.86 cm around the fourth season in June and July. The minimum soil water storage was estimated 5.18 cm in the second season of the modeling year in January, February, March and somehow April which is dry with no significant rain fall. There is little difference in soil water storage and cumulative infiltration between AC and ACE (i.e. Area closure with engineering structures). ACE which is under closure and treated with structures has around 10.604 cm mean soil water storage with pick value 17.3 cm in the fourth season which is rainy and 5.27 cm during dry season of the modeling year. When we compare these two sites in terms of soil water storage ACE which is area closure with engineering structures has better soil water storage than the AC area closed site that's considered as under controlled situation. The modeling results of mean soil water storage of cultivated lands under watershed management practices (CLF0) and controlled (CLF1) situations expose that, CLF0 has better water storage than the controlled CLF1 with 15.38 cm and 14.22 cm SWS results respectively. The pick values was registered during wet season of the modeling year around June, July, August and somehow in September and maximum estimated value is 21.37cm and 19.98 cm respectively for CLF0 and CLF1. However, the minimum value is at dry season from December to April which is 9.833cm and 9.14 cm for those cultivated lands under watershed management and controlled sites, CLF 0 and CLF 1 respectively. Generally, CLF 0 has better soil water storage throughout the year including the dry season of the year with no significant rainfall. In the contrary to this, slight difference in the mean daily soil water storage of CLG0 which is cultivated land under watershed management practices was lower than that of CLG1 which is under controlled situation. Hydrus 1D simulation result of soil water storage for CLG0 and CLG1 was 12.06 cm and 13.23 cm respectively. As usual, the maximum amount has registered in July during the wet season and 18.75 cm SMS is recorded for CLG 0 which has also minimum amount of 7cm SMS in April that's in the dry season mostly the second and partially the third season of the modeling year. From the in situ measured soil physical property results, CLG 0 which is under watershed management has lower bulk density and higher Ksat values. However, in the in situ measured soil physical properties, CLG 1 was characterized by higher bulk density and lower $K_{sat}$ value. Therefore, this property can also be the indicator of slow water flow within the pore spaces and higher soil water storage. Note that, CLG 0 was with better Bottom flux value than CLG 1 in the modeling result. Finally, the daily mean soil water storage of the last two pair of land management classes CLS0 which is under watershed management practices and CLS1, controlled was simulated as 11.35 cm and 10.37 cm respectively. In both dry and wet seasons water storage of CLS 0 is much better than that of CLS 1 with maximum 17.53 cm around July and minimum 6.73 cm during the dry season of the modeling year in January, February and March. SMS in CLS1 was 16.72 cm maximum and 5.52 cm minimum simulated values during those mentioned wet and dry periods of the modeling year.



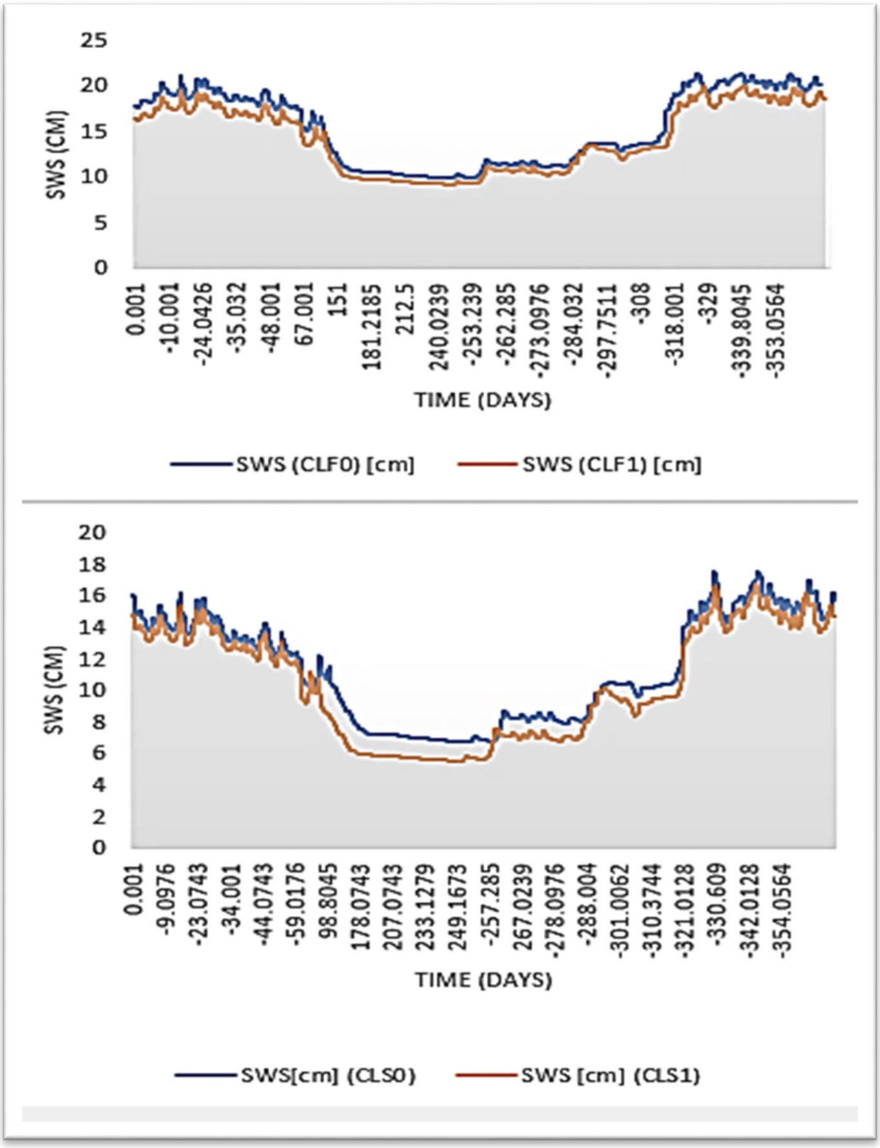
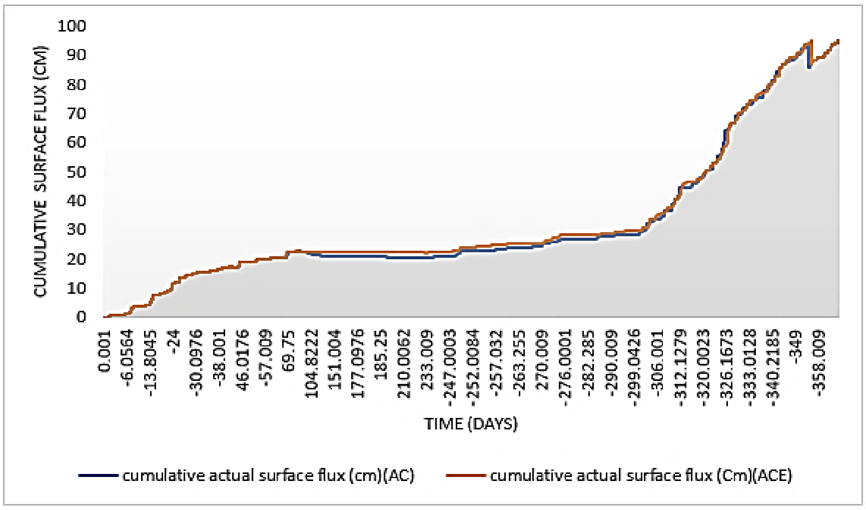


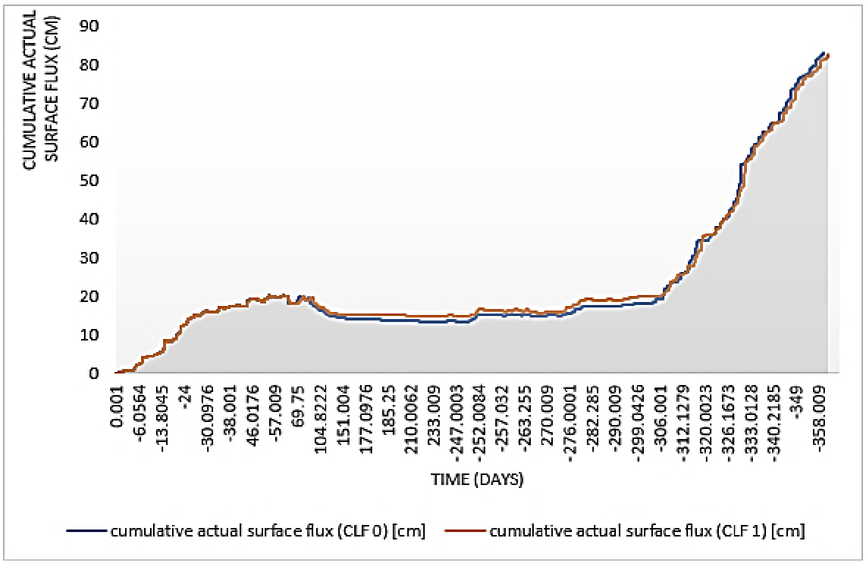
Figure 13. Simulated SWS of comparable sites in different LM style

## Surface Fluxes

Surface flux is near surface one directional flow of water to the soil profile. Hydrus 1D has estimated actual surface flux of all sites under WSM and controlled conditions. The simulation results of actual surface fluxes which are in flow of water near ground surface in the pore space of soil for the AC is better than that of ACE with 0.0299cm/day and 0.0253 cm/day above ground surface. The mean flux estimated in the model is -0.470 cm/day and -0.467 cm/day for AC and ACE respectively. However, in the dry season (i.e. from November to May) cumulative flux of the ACE is comparatively better than that of the AC as plotted in the graph (Figure 14). For the cultivated lands under watershed management practices, maximum actual surface flux was to be estimated as 0.35 cm/day, 0.35 cm/day, and

0.348 cm/day for CLF 0, CLG 0 and CLS 0 respectively. The maximum actual surface flux under controlled environment was 0.35 cm/day in CLF1, 0.35 cm/day in CLG1, 0.348 cm/day in CLS1 which has very small difference with values of flux in sites under WSM. However, the cumulative actual surface flux was 83.08 cm and 82.565 cm for CLF 0 and CLF 1, 82.76 and 82.13 cm in CLG 0 and CLG 1, 85.6 and 82.9 cm in CLS 0 and CLS 1 respectively. The mean surface flux estimated in CLF0, CLG0 and CLS0 sites was -0.453 cm/day, -0.424cm/day and -0.443 cm/day respectively. When this value is compared with the mean daily actual surface flux of sites under controlled situation (i.e. CLF1, CLG1, CLS1 estimated - 0.454 cm/day, -0.431cm/day and -0.425 cm/day) respectively, those sites under WSM practices was with better mean surface flux except in the case of CLS0 versus CLS1 comparison.





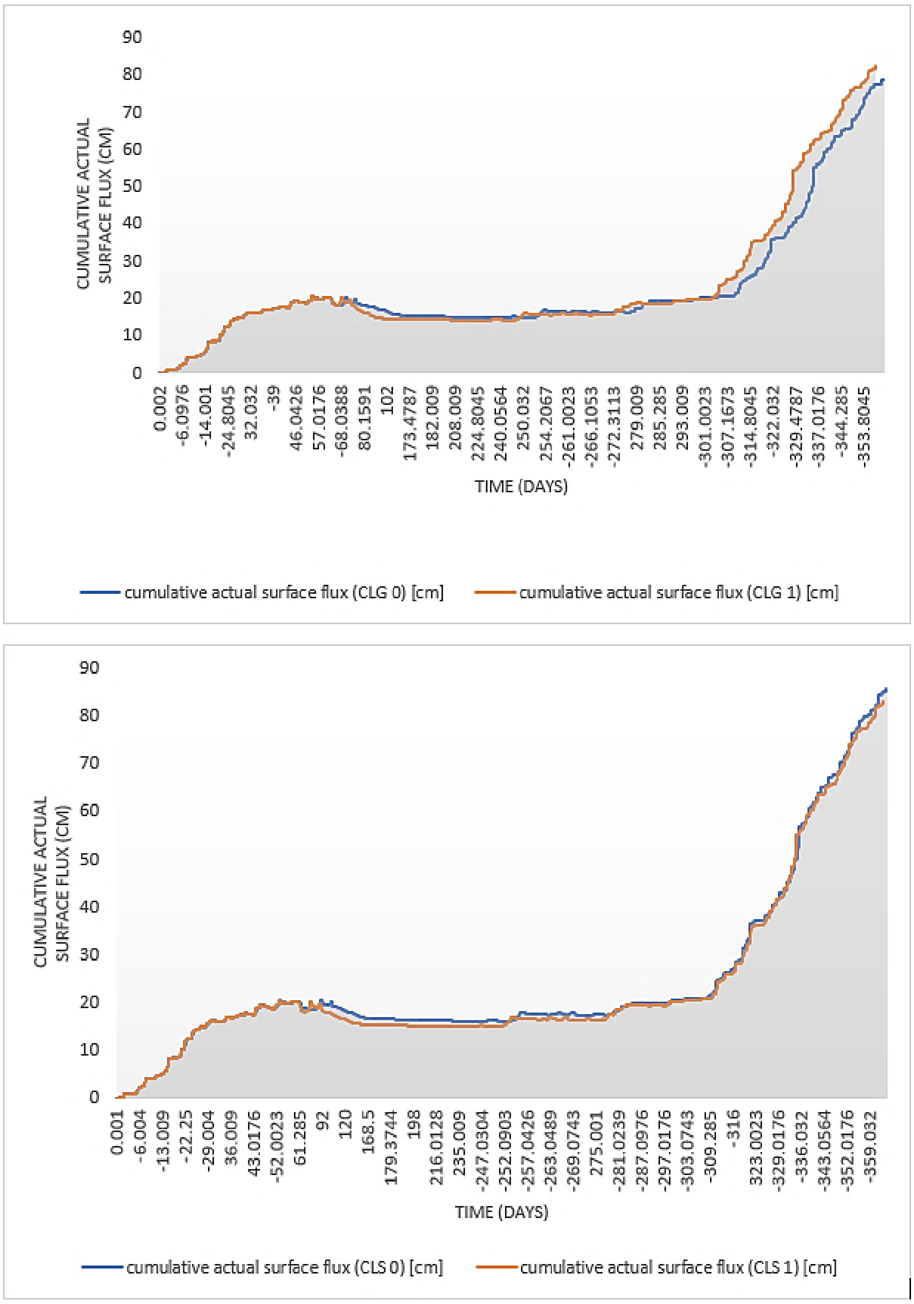


Figure 14. Cumulative actual surface flux of all sites within 365 days

## Infiltration

Infiltration is the flow of water from the surface of the ground in to the pore spaces of soil profile. Cumulative infiltration of the area closure (AC) was estimated to be 98.327cm for the study period which is almost the same as ACE which is also area closure with engineering structures of soil and water conservation measures, thin soil of gentle- steep slope area. In the case of cultivated lands under WSM and controlled environment, CLF0 and CLF1 have very little difference of infiltration estimated as 115.05 and 115.23 cm cumulative infiltration registered. The cumulative infiltration of CLG0 and CLG1 was also 115.05 and 115.23 cm respectively that's almost the same as CLF0 and CLF1. In the case of CLS0 and CLS1 simulated cumulative infiltration was 115.02 and 115.03 cm respectively.

## Bottom Fluxes

The bottom flux here represents deep drainage below root water uptake zone (Hydrus 1D manual) which recharges ground water below the ground. From the collected ground water level data of existing hand dug wells; the ground water table of the area is mostly deep as 12-25 meters below the surface. So, this couldn't affect our model simulation result due to ground water flow towards surface root uptake zone. Based on this, when we compare the bottom flux of AC and ACE which was modeled as 0.408 cm/day and 0.378 cm/day respectively the areal closed site has slightly higher value in recharge( mean bottom flux ) with 0.03cm/day mean bottom flux difference. Most of the results of bottom fluxes of AC and ACE are very close to each other since both land management types are closed areas. The only difference between the land management of the two sites is combined effect of Engineering structures with area closure technique has been applied to keep the sites treated in terms of sustainable watershed management in ACE. The second land group under study was the cultivated land under different watershed management practices. The mean daily bottom flux in CLF0 is 0.33 cm/day that's slightly better than CLF 1 which has 0.325 cm /day mean daily value. The annual cumulative bottom flux in these sites, CLF0 and CLF1 was also 83.08 cm and 82.565 cm respectively. Even though the results seem very close to one another comparatively there was better cumulative bottom flux estimated in CLF0 that's under WSM than the controlled CLF1(Figure 15) . In CLG0 which was under WSM, the simulated mean daily bottom flux value was 0.328 cm/day. This was better estimated bottom flux than CLG1 site which is 0.322 cm/day in a very small amount. The cumulative annual bottom flux was estimated to be 82.8cm for CLS0 and 79.8 cm for CLS1. Based on this, the annual cumulative flux value of the treated land under WSM practices (CLS0) was comparatively better than the untreated, controlled cultivated land, CLS 1. Similarly, the mean daily bottom flux value of CLS0 which was under WSM practices showed better simulation result than that of untreated controlled site, CLS1 with flux value of 0.44cm/day and 0.425 cm/day mean daily result. When the annual cumulative bottom fluxes values of the two sites were compared, CLS0 has higher flux with 85.6 cm than CLS1 which has

82.9 cm bottom flux value annually (Figure 12). During dry season of the year, better cumulative bottom flux values have been observed on sites under watershed management practices than that of untreated sites (Figure 12). This makes water available in the area in the absence of rainfall during meteorologically dry time.

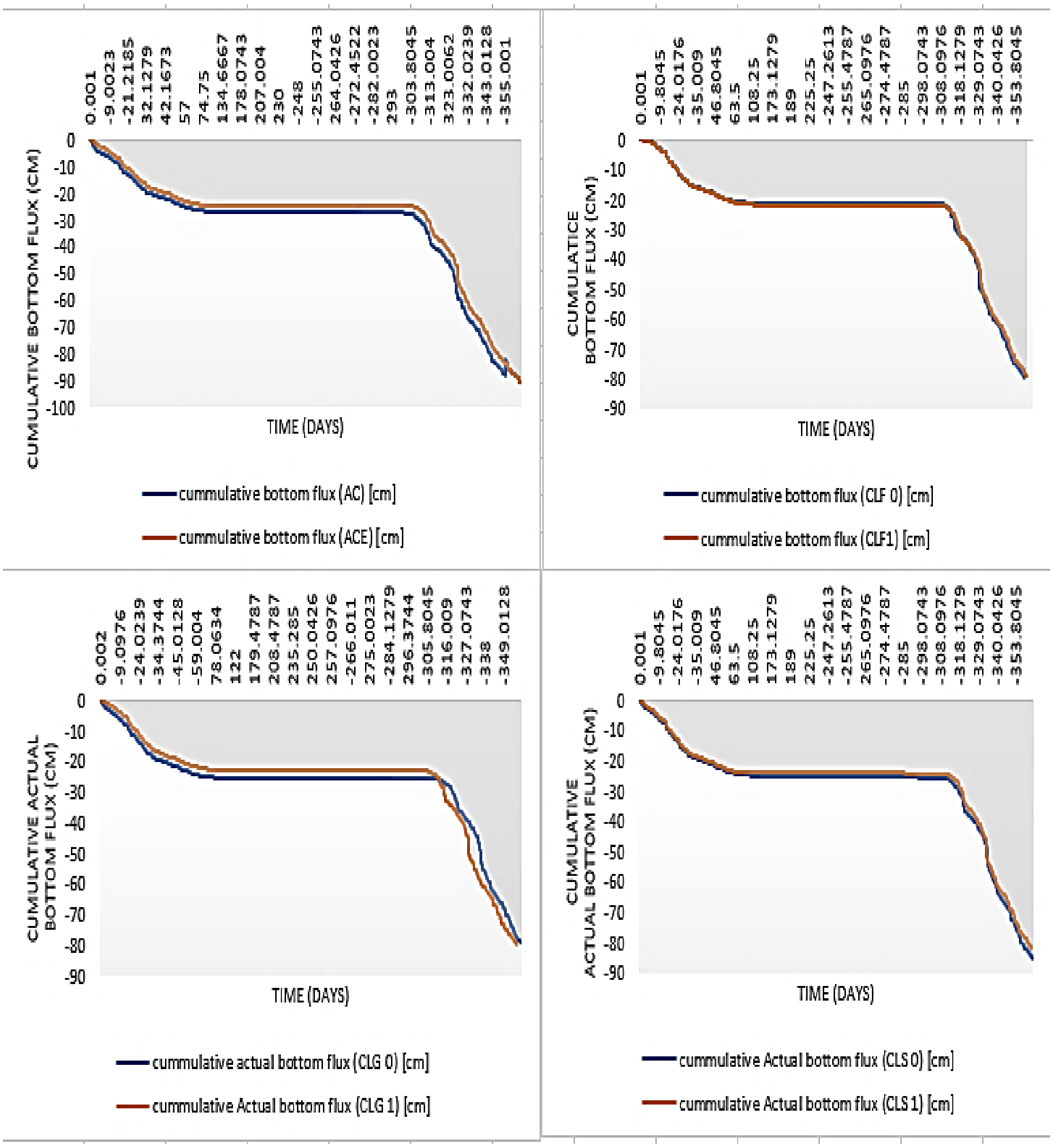


Figure 15. Cumulative actual bottom flux

## Root water uptake

In Hydrus 1D model, simulation of Root water uptake represented the transpiration of water from the leaves of crops and plants. The dominant vegetation type to be taken to the model as an input to estimate transpiration were grass in the area closures (i.e AC and ACE), Finger millet in the cultivated lands CLF0 and CLF1, Maize in CLG 0 &

CLG1, CLS0 & CLS1. Based on this, root water uptake of ACE is comparatively higher than that of AC since the plant density in ACE is higher than that of AC which is degraded land under controlled environment. The mean daily root water uptake of the grass in AC and ACE was estimated to be 0.0204 and 0.0218 cm/day respectively. The comparison between the mean daily root water uptake of sites under watershed management practices versus those sites under controlled environment was estimated as 0.0215 cm/day in CLF 0 and 0.00452cm/day in CLF1; 0.00445 cm/day in CLG0 and 0.00464 cm/day in CLG1; 0.0019 cm/day in CLS0 and 0.0047 cm/day in CLS1. The Hydrus 1D model was estimated higher root water uptake values under untreated controlled sites than that of sites under watershed management practices. This difference is one indicator of high transpiration of water in the untreated sites than those sites under watershed management practices. It can also clearly emphasize that there was higher amount of remaining available water in the soil or below the root zone of those sites under WSM than the untreated controlled ones.

## Evaporation

Evaporation in Hydrus 1D model represents outflow of water from bare soil, water bodies and water from any surface of material in the form of vapor. Hargreaves method was selected to estimate Evaporation at each site since there is scarcity of data and Hargreaves formula only requires daily Max-Min temperature and average daily precipitation data to compute Evaporation. Based on this, the cumulative evaporation in the AC exceeds ACE as estimated in Hydrus 1D model output, 4.7cm for AC and 3.3 cm for ACE. This was wide gap for the same treated lands under WSM, only differ by engineering structures and it can indicate the role of Engineering structures like terraces in minimizing surface Evaporation. In the cultivated lands 32 cm cumulative annual evaporation was estimated for CLF0 and 32.7 cm for CLF1, 32.27 cm for CLG0 and 32.905 cm for CLG 1, 29.424 cm for CLS0 and 32.137 cm for CLS1. Huge difference in cumulative evaporation value was resulted in the model output between area closed lands and cultivated lands even though those cultivated lands are under watershed management practices. These values indicate that area closure might be one of the best watershed management practice type. On the top of that, combined effect of area closure with other WSM structures brought even higher result in minimizing evaporation.

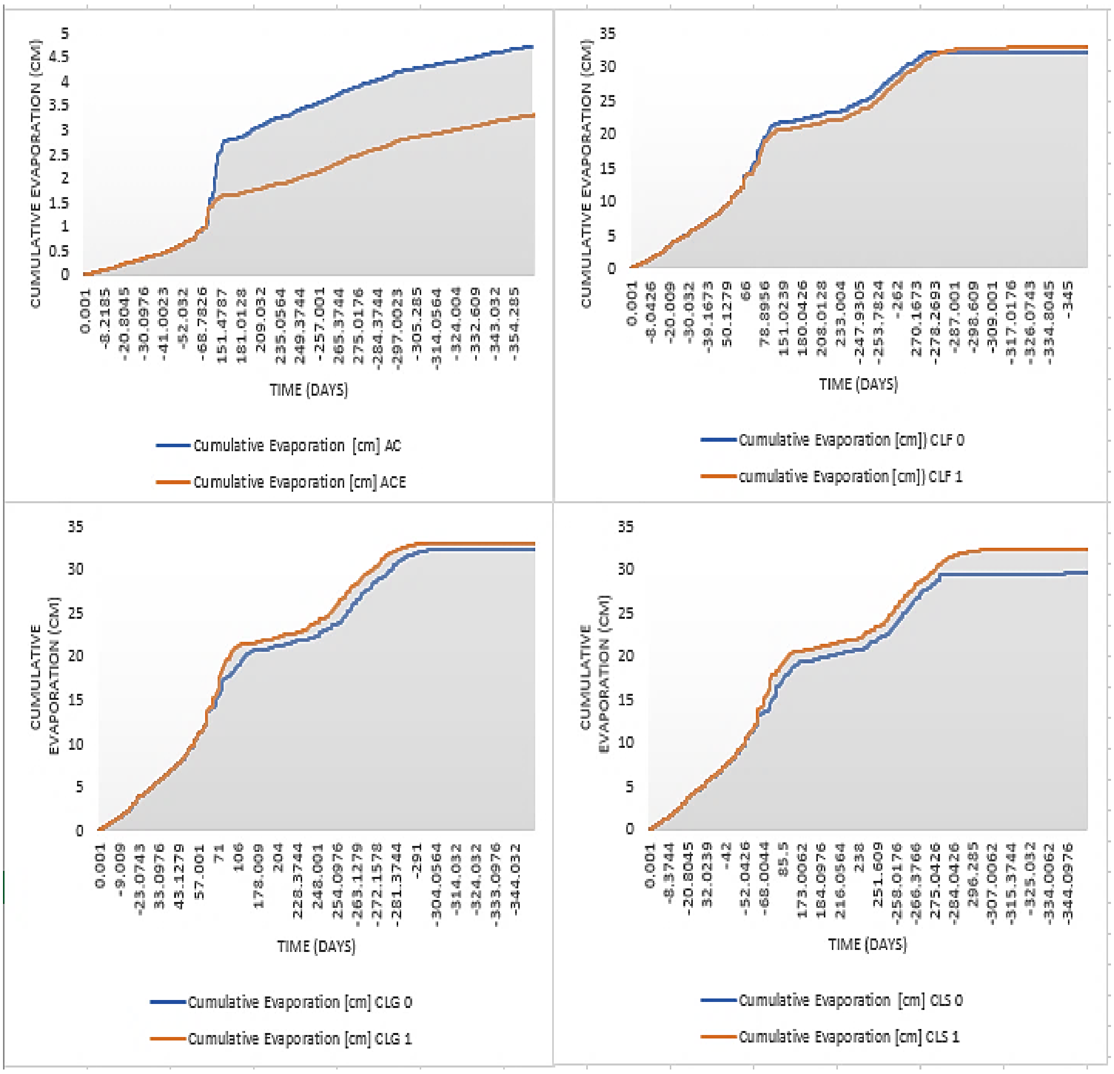


Figure 16. Cumulative Evaporation of all sites within 365 days

### 4.1.3. Evaluation of model performance and parameter identification

From the collected soil hydrological data, 365 days' time series of volumetric soil moisture data was collected at different depths 100, 200, 300 and 400 mm, in 8 different sites used to calibrate the results of Hydrus 1D SM results. Therefore, the in situ measured soil water content was used to evaluate the performance of the model. Inverse solution method was applied to calibrate the simulated soil water content with respect to measured soil water content. Based on this, Hydrus 1d model made some statistical calculations to determine the efficiency of the model and provide the corresponding results under inverse solution output information. ME, NRMSE and MRE values for each site was calculated with the inverse solution function of hydrus1D. In some of the plots that represent soil moisture versus time in some sites, there wasn't visible graph for measured soil moisture data since we used the mean value of soil moisture data for calibration purpose which doesn't represent any single layer and Hydrus 1D couldn't recognize its layer position to display. However, the ME, MAE, NRMSE and R-square values are displayed in the output post process display as an output for inverse solutions. In Hydrus 1D model, Simulation result of Soil water content of different layers could be calibrated with measured values of soil moisture content record of any layer that can provide better statistical fit with the simulated estimations. Based on this,

Site 1- calibrated and best fitted with measured theta values at 200mm depth.

Site 2- calibrated and best fitted with measured theta values at 100mm depth.

Site 3- calibrated and best fitted with measured theta values at 200mm depth.

Site 4- calibrated and best fitted with measured theta values at 400mm depth.

Site 5- calibrated and best fitted with theta values at 100mm depth.

Site 6- calibrated and best fitted with measured soil moisture content data at mean value of theta of the four observation points (100,200,300,400 mm) depth.

Site 7- calibrated and best fitted with measured theta values at 200mm depth.

Site 8- calibrated and best fitted with measured theta values at 100mm depth were the layer soil moisture recordings that has being applied in this study to calibrate simulation results of Hydrus 1D.

The below graphs represent that the calibration of simulation results of soil moisture content in different layers for the eight experimental sites site 1 (AC), site 2, (ACE), site 3(CLF0), site 4(CLG0), site 5 (CLS 0), site 6 (CLF1), site 7 (CLG 1) and site 8 (CLS1).

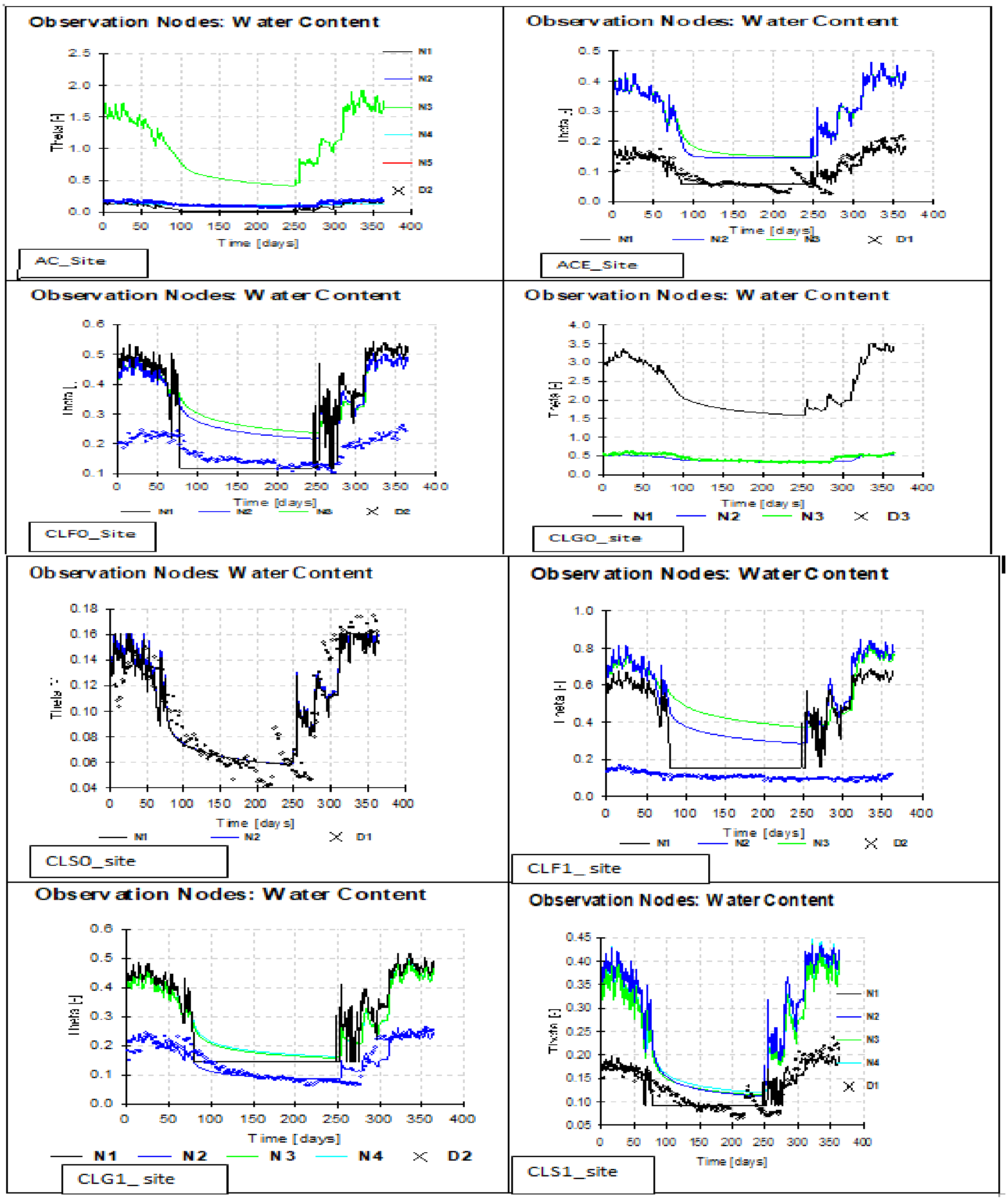


Figure 17. Simulated versus measured SM data of all sites

Simulated SM in the above output graphs of Hydrus 1D plotted for each single node (N) that represent each layer of soil material has represented by unique color in the plots. Each observation node N represents the soil layers. Based on this, the simulation result of soil water content for a model was calibrated by any single layer time series reading of soil water content including the average soil water content that best fits the simulation result. The following Table (Table 10) presents some statistical parameters to test the model performance.

| Sites | Model performance | | Sites | Model performance | |
|---|---|---|---|---|---|
| AC | ME | -8.65E-04 | CLS 0 | ME | -3.91E-05 |
| | MAE | 1.07E-02 | | MAE | 1.43E-02 |
| | RMSE | 1.52E-02 | | RMSE | 1.98E-02 |
| | $R^2$ | 0.85752 | | $R^2$ | 0.77583 |
| ACE | ME | -1.54E-05 | CLF 1 | ME | -5.33E-02 |
| | MAE | 1.96E-02 | | MAE | 5.77E-02 |
| | RMSE | 2.59E-02 | | RMSE | 8.57E-02 |
| | $R^2$ | 0.77051 | | $R^2$ | 0.54623 |
| CLF 0 | ME | -1.56E-01 | CLG 1 | ME | 7.83E-05 |
| | MAE | 1.56E-01 | | MAE | 2.24E-02 |
| | RMSE | 1.69E-01 | | RMSE | 3.07E-02 |
| | $R^2$ | 0.77466 | | $R^2$ | 0.77968 |
| CLG 0 | ME | 1.14E-02 | CLS 1 | ME | -4.11E-05 |
| | MAE | 3.29E-02 | | MAE | 1.83E-02 |
| | RMSE | 4.38E-02 | | RMSE | 2.44E-02 |
| | $R^2$ | 0.79284 | | $R^2$ | 0.73186 |

Table 9. Level of agreement between measured and simulated SM data

(ME; Mean Error, RMSE; Root mean square error, MAE; Mean weighted absolute error; $R^2$ , Statistical measure of goodness of fit)

## 4.2. Discussion

This study, the implication of watershed management practices on water availability of Aba Gerima watershed was mainly planned to examine the water availability implications of watershed management practices carried out in Aba Gerima watershed. The study was conducted through analyzing soil physical and hydrological properties, evaluating different water balance components and hydrological parameters using Hydrus 1D model in different land management practices and examining the implication of sustainable watershed management practices on the study sites comparative hydraulic properties within the study time frame 365 days.

On the top of studying in situ measured soil physical and hydraulic properties data the study estimated water balance component of each study site with Hydrus 1D model to compare simulation results of water balance components and quantify water availability in each of the 8 study sites. According to field observation and baseline survey report WLRC (2012), enormous amount of works has been done on sustainable land management practices in Aba Gerima watershed from 2012. Even though some of the structures are damaged currently, it's still clearly visible that the area was highly conserved once up on a time in terms of environmental protection and land management aspects. However the watershed management work implemented once up on a time was not sustainable due to many reasons and there was also data management gap in the area to conduct further works. Based on this, hopefully this study have filled some of these gaps by studying, the impact of watershed management practices on water availability in Aba Gerima using limited collected data, field observations and previous study findings on the study area.

### 4.2.1. Impacts of WSM practices on soil physical properties

According to Tefferi (2016) On the study conducted in one of the Ethiopian highlands to determine the impact of LULC and LM on soil quality, revealed that soil texture, organic matter content, bulk density, and soil pH were found to be appropriate soil quality indicators that are related to land use or/and altitude. The out puts of the study were also supported with the findings of other scholar Tesfahunegn (2013), who investigated sustainability of land use or management, is evaluated mainly with important parameters like soil organic carbon, silt content, and bulk density. From field observations in Aba Gerima, Land management practices in the watershed highly influenced the surface topography and slope, consequently impacted water availability of the area through affecting soil physical properties like bulk density and Sand, silt clay and organic content composition of soil. The findings in this study, the declining of soil layers saturated hydraulic conductivity downwards with depth in those sites under watershed management practices than in controlled sites was supported the findings of those above mentioned literatures. In other words, this can indicate that the deep percolation or rate of recharge beyond the root uptake zone is higher in sites under watershed management practices which is clearly observed in Hydrus 1D simulation results in this study.

### 4.2.2. Impacts of soil physical properties on soil hydrological properties

In this study soil physical parameters such as, textural composition (sand, silt, clay percentage) and bulk density of soil was used as an input to predict soil hydraulic parameters in Rossetta v.1.1 (June,2003). Soil hydraulic parameters; residual water content ($cm^3/cm^3$), Saturated water content ($cm^3/cm^3$), Alpha coefficient (1/cm), n parameter (-), saturated hydraulic conductivity (cm/day) were predicted. In situ measured Ksat was applied to compare the results with simulated one and it’s clearly seen that soil bulk density ($g/cm^3$) has high role in determining Ksat of the soil layer. In addition to this, Residual and saturated moisture contents of a soil layer were also highly dependent on physical properties of soil layer like sand, silt, clay ratio and especially on soil layer bulk density. Likewise Land management highly affects Land use and slope of the area, both LULC and altitude has also significant implications on soil layer bulk density which is the main factor in determining soil hydrological properties. According to Neill et al. (1997) a significant increase in bulk density has been observed after the conversion of forest to grassland. The study of Wang et al. (2015) in the spatial variability of SWRC (VG model) on the Loess Plateau also obtained a basic relationship between soil bulk density and VG parameters that BD highly influences the VG parameters variation (except for α). Moreover, Biswas and Si (2009) obtain great influence of bulk density on soil hydrologic properties and investigated significant correlation of bulk density with the VG parameters (except for α) and Ks. In our study results of Aba Gerima watershed also average bulk density of those sites under watershed management practices decreases down towards the bottom layers than the surface layers however, the reverse is true in layers of the controlled sites which are untreated in terms of watershed management. The impact of this relationship has been seen clearly on Hydrus 1D model simulation results of Infiltration, soil water storage, actual surface and bottom fluxes of those sites. Based on this, the graphs of bottom flux and cumulative infiltration of sites under watershed management practices grows up while soil bulk density and respective hydraulic conductivity decreases towards the bottom layer. Generally, watershed management practices influence available water in an area through positively contributed to bulk density of the soil layers of the area.

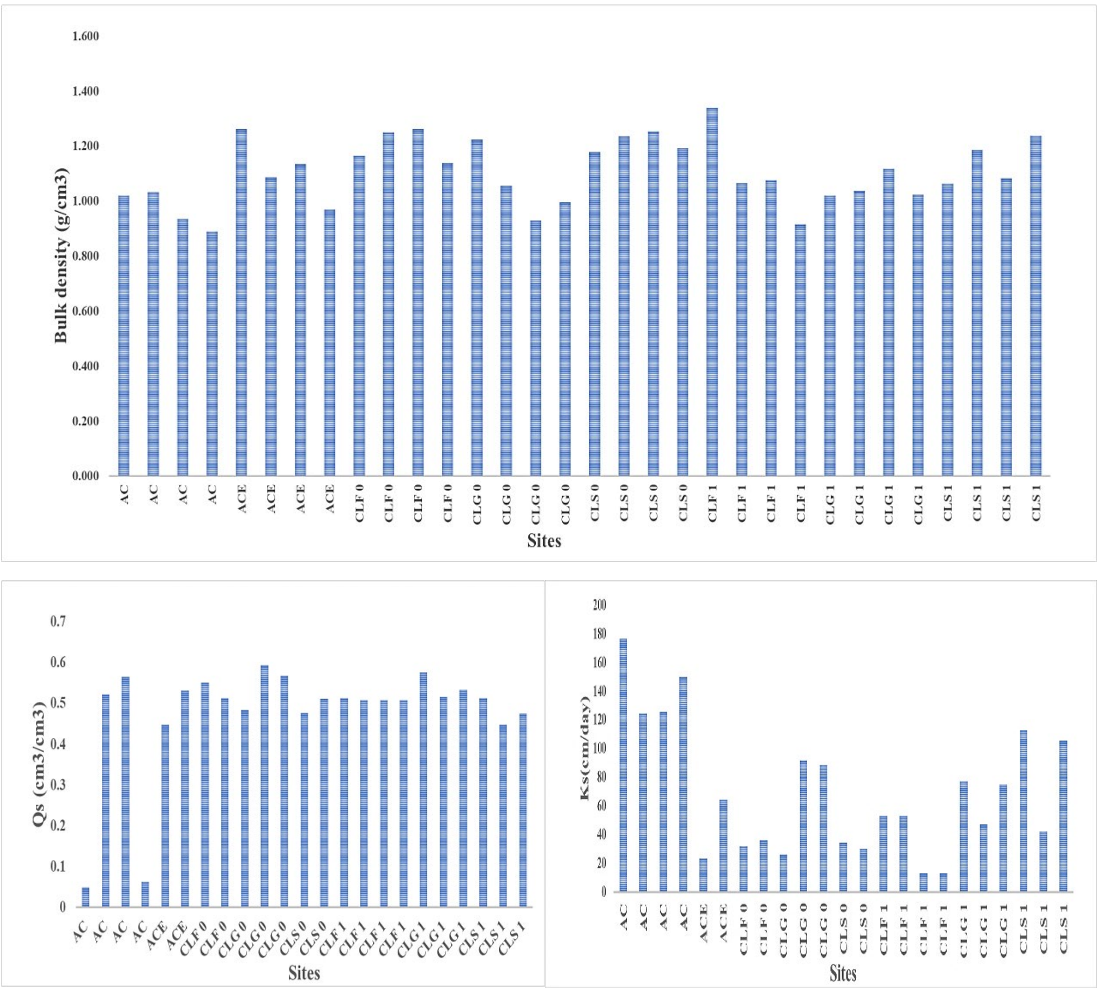


Figure 18. Estimated soil hydraulic parameters from measured soil layer BD

### 4.2.3. Implications of watershed Management on water availability

Water availability of a watershed is manifested by the water balance components that feed positively to the system like recharge, soil water storage, infiltration and base flow. The water balance components like Evaporation, transpiration, surface run off can be denoted as outflow components that abstract water from the system. Studies regarding watershed management and watershed management practices indicate that watershed management practices have a significant contribution on hydraulic properties of the watershed. (Sultan et al., 2018; Tefferi et al., 2016). Watershed management practices are also mostly expected to improve water availability components of the system and minimize water balance components that play negative role in water availability of the watershed. Similarly in this thesis also, Hydrus 1d model simulation results of water balance components revealed that sites under watershed management practices was better in water availability than untreated controlled sites. Water availability was described in terms of water balance components; such as, infiltration, soil water storage, surface flux, bottom flux, evaporation and transpiration. In other words, water balance components that feed the system positively were higher in sites under WSM and components such as evaporation and surface run off were lower. The mean daily recharge or actual bottom flux amount in those treated sites has to be simulated 4.088 mm/day and 3.77 mm/day for area closed AC and for ACE which is closed area with engineering structures. It's also estimated that 4.7066 mm/day and 4.697 mm /day mean daily actual surface flux for AC and ACE respectively that's still better in terms of water availability in the managed ACE site. Bayabil et al. (2015) on the study to determine surface runoff with sediment yield in one of upper blue Nile basin estimated surface run off up to 820 mm/year which is very similar to our Hydrus 1D estimation of surface flux that includes base flow and surface runoff ranges 821 mm/year to 951 mm/year. There might be mixing of surface and bottom flux estimations in our study since the thickness of soil profile under the study is only 40 cm and Hydrus 1D model took all fluxes under the root depth of vegetation as a bottom flux. Since both sites, AC and ACE are under watershed management practices, the small difference in result has to be taken as the impact of those additional engineering structures done on ACE. Similarly, ACE has better soil water storage with 106.039 mm annual cumulative soil water than AC, 100.37mm. When we compare AC and ACE in terms of evaporated water out from the surface of the land, 46.967mm and 32.898 mm annual cumulative value still ACE has better result in preventing evaporation and contribute positively to water availability of the watershed. Actual Evaporation estimated in the area has to be 488 mm/yr in Gumara catchment (Tekleab et al., 2011).

The results for the remaining sites are also under the acceptable range of results from different studies worked previously on water balance components of the area (Tekle ab et al., 2011, Sultan et al., 2018, Ayenew et al., 2008, Beyene et al., 2018). Daily mean bottom flux of the remaining treated sites under watershed management practices has estimated to be 3.33 mm/day, 3.28 mm/day, 3.5 mm/day for CLF0, CLG0 and CLS0 respectively. The comparison of results in the mean daily bottom flux of untreated sites, 3.2 mm/day for CLF 1, 3.2 mm/day, 3.33 mm/day for CLG1 and CLS1 respectively with the respective sites under watershed management practices clearly indicated that sites under WSM has better recharge capacity than these untreated controlled sites. There was also significant difference between those groups of sites in terms of soil water storage. The average SWS in those sites under WSM were better than the controlled untreated sites. Annual soil water storage of sites under watershed management practices was, 100.37mm ,106.04 mm, 153.76mm,120.58 mm, 113.5 mm for AC, ACE, CLF0, CLG0, CLS 0 respectively and 142.3mm for CLF1, 132.4 mm for CLG1, 103.7 mm for CLS1 which are untreated & controlled ( i.e compare results of AC Vs ACE, CLF0 Vs CLF1, CLG0 Vs CLG1, CLS0 Vs CLS1)

In some cases, Sites under WSM such as CLG0 has lower soil water storage than the respective controlled cultivated land CLG1 because of higher hydraulic conductivity of the bottom layer made cumulative bottom flux (recharge) higher in CLG0 and as a result the respective soil water storage becomes comparatively smaller throughout near surface soil layers.

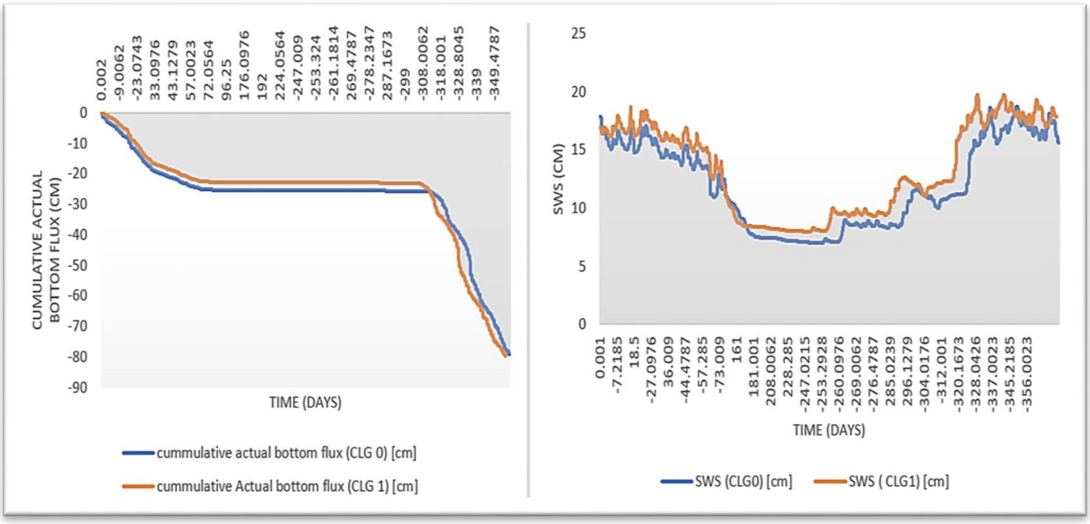


Figure 19. (a) Soil water storage (b) cumulative bottom flux of CLG 0 and CLG 1

Generally, based on the Hydrus 1D simulation results summarized below, these treated sites, under WSM practices (AC, ACE, CLF0, CLG0, CLS0) has estimated to have 95.166mm, 95.17 mm, 83.08 mm, 82.76 mm 85.6 mm cumulative surface flux respectively and 82.56 mm for CLF1, 82.126 mm for CLG1, 82.894 mm for CLS1 cumulative surface flux was simulated for controlled sites on Hydrus 1D model.

| No | Site | Under watershed management practices (Mean) | Controlled (Mean) |
|---|---|---|---|
| 1 | Mean Actual Surface flux (cm/day) | 0.45 | 0.436366667 |
| 2 | Annual Cumulative Infiltration (cm) | 108.348 | 115.1633333 |
| 3 | Mean Actual Root water uptake (cm/day) | 0.01008 | 0.004566667 |
| 4 | Cumulative Evaporation(cm) | 20.3324 | 32.56966667 |
| 5 | Mean SWS (cm) | 11.8834 | 12.613 |
| 6 | Mean Bottom flux(cm/day) | 0.3596 | 0.325666667 |

Table 10.Summarized mean daily and cumulative water balance components in WSM and controlled sites

# Chapter 5

# Conclusion and Recommendations

## 5.1. Conclusions

This thesis was organized to address the question how WSM practices contribute to availability of water in Aba Gerima watershed within the study period. The study was conducted with the main objective of finding the implication of WSM practices on availability of water in the study area through collected and data from sites under WSM practices and controlled situations with Hydrus 1D model. Specifically, in addition to modeling of water balance components at each site, in situ measured soil physical and hydrological properties were examined to study its relationship with respect to WSM practices. In this study the same precipitation and temperature, slope, crop type and sampling depth conditions were used to determine soil water balance of the respective comparable sites under different land management conditions. Hydrologic or water balance components such as Surface flux, bottom flux, infiltration, soil water storage, Evaporation and Root water uptake of each site were simulated with the Hydrus 1D model. The output results of each water balance component were analyzed to compare the results for sites under controlled Environment with their equivalent sites under WSM practices. Good agreement has been observed between simulated and observed values and the model more or less predicted the results in a good manner.

From the study result, water availability of sites which are under watershed management practices was better than that of sites under controlled environment. Specifically, the impact of WSM practices to change soil physical properties in the study sites were addressed with examining the implication of soil physical properties on soil hydrology. This was done through studying how Soil physical properties such as soil texture and bulk density was also the main responsible factors to affect soil hydrology from neural network prediction of Rosetta_Lite v 1.1(June, 2003).

Generally, watershed management practices in Aba Gerima watersheds was brought a good result in increasing water availability of the area through maximizing recharge, surface flux and soil water storage and minimize evaporation, transpiration and surface run off in the study sites especially during dry time of the study period.

## 5.2. Recommendations

Enormous amounts of works have been done in Aba Gerima watershed to rehabilitate the degraded Aba Gerima watershed in to enhance productivity & keep better natural condition since 2012. It was conducted well for many years since the watershed management project scrambled & stopped after 5 years excellent work. From field observations, the WSM practices done in Aba Gerima such as, terraces, trenches, area enclosures, biological structures were damaged partially & facing huge distruction due to lack of follow up. As a consequence, better results obtained during the implementation of WSM project were turning back during our field observation of hand dug wells and discussion with the villagers. Based on their explanation, even though the number of hand dug wells in the watershed increases time to time, sustainability of those drilled wells were improved highly during the WSM project implementation years.

Now days, some of physical and biological structures are damaged, terraces collapsed, trees cut and closed areas become open for free grazing and fuel wood collecting areas. These damages on those structures started to manifest its consequences on the watershed in terms of soil erosion, land infertility & water scarcity. Decreasing discharge of springs and water wells, high rain time surface run off, decrease of surface fluxes in dry seasons, soil erosion and gully formation has being seen time to time with failing and damaging of WSM practices. This is also supported by the outputs and findings of this paper.

From this, it’s highly recommended that the WSM projects in that area should be resumed again as soon as possible before the environment gets back to its earlier degraded situation. On the top of this, different Watershed management practices should be applied depending on different site conditions like slope, soil type, water table status, presence of available local material. Based on this, Baseline surveys and studies should be conducted side to side of applying watershed management practices to determine which kind of watershed management practices or soil and water conservation practice would be more efficient for the specific local area.

Furthermore, since community participation is the backbone and basic column to stand the watershed management practices sustainably one should work on community’s attitude before designing the physical works on the site.

So, I have concluded my paper with serious recommendations that the watershed management practices in that area should be re launched by studying the current appearance of the structures and participating the community to commit and involve on these practices for better environmental and economic benefits. In addition to this, watershed management practices should be extended to every small watersheds throughout Ethiopia with scientifically guided site specific studies, plans and programs since specific WSM practices brought this much results in such a small watershed like Aba Gerima, 900 ha.

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# Appendices

**Appendix 1. Sample Meteorological data**

| Aba Gerima /Bahrdar station | | | | |
|---|---|---|---|---|
| Date | MIN T(°C) | MAX T (°C) | AVG T(°C) | RF(mm) |
| 9/1/2017 | 13.8 | 25.5 | 19.7 | 1.6 |
| 9/2/2017 | 15.6 | 27.5 | 21.6 | 4.8 |
| 9/3/2017 | 16.8 | 26.0 | 21.4 | 2.8 |
| 9/4/2017 | 15.0 | 26.0 | 20.5 | 4 |
| 9/5/2017 | 15.4 | 25.0 | 20.2 | 9 |
| 9/6/2017 | 14.6 | 26.5 | 20.6 | 27.8 |
| 9/7/2017 | 14.5 | 26.0 | 20.3 | 0 |
| 9/8/2017 | 14.0 | 26.5 | 20.3 | 6 |
| 9/9/2017 | 14.4 | 26.5 | 20.5 | 0 |
| 9/10/2017 | 15.4 | 26.0 | 20.7 | 0 |
| 9/11/2017 | 15.0 | 26.5 | 20.8 | 5.4 |
| 9/12/2017 | 13.5 | 27.0 | 20.3 | 7.8 |
| 9/13/2017 | 14.5 | 25.5 | 20.0 | 7 |
| 9/14/2017 | 13.0 | 26.0 | 19.5 | 5.8 |

| | | | | |
|---|---|---|---|---|
| 9/15/2017 | 14.0 | 25.0 | 19.5 | 22.8 |
| 9/16/2017 | 13.5 | 26.4 | 20.0 | 3.6 |
| 9/17/2017 | 14.0 | 26.0 | 20.0 | 19 |
| 9/18/2017 | 14.2 | 27.5 | 20.9 | 3.4 |
| 9/19/2017 | 14.6 | 27.0 | 20.8 | 7.4 |
| 9/20/2017 | 15.2 | 27.5 | 21.4 | 1 |
| 9/21/2017 | 14.2 | 28.0 | 21.1 | 11.8 |
| 9/22/2017 | 13.6 | 28.0 | 20.8 | 5 |
| 9/23/2017 | 14.0 | 27.5 | 20.8 | 3.2 |
| 9/24/2017 | 15.2 | 27.2 | 21.2 | 0.2 |
| 9/25/2017 | 15.6 | 27.4 | 21.5 | 0.4 |
| 9/26/2017 | 14.2 | 27.5 | 20.9 | 4.2 |
| 9/27/2017 | 14.2 | 28.5 | 21.4 | 10 |
| 9/28/2017 | 14.6 | 28.0 | 21.3 | 0.2 |
| 9/29/2017 | 15.8 | 29.0 | 22.4 | 2.6 |
| 9/30/2017 | 14.4 | 27.5 | 21.0 | 8 |

## Appendix 2. Sample crop type and growth data

| | Maize height (cm) | | | Finger millet (cm) | | |
|---|---|---|---|---|---|---|
| Time/days | Height | Root depth (Flat slope) | Root depth (Gentle and steep) | Height | Root depth (Flat slope) | Root depth (steep and Gentle slope) |
| 300 | 24.25 | 10.6527561 | 8.522204882 | 23.28 | 10.18403483 | 8.14722787 |
| 301 | 25.55 | 10.86581122 | 8.69264898 | 24.528 | 10.38771553 | 8.31017242 |
| 302 | 26.85 | 11.08312745 | 8.866501959 | 25.776 | 10.59546984 | 8.47637587 |
| 303 | 28.15 | 11.30479 | 9.043831999 | 27.024 | 10.80737924 | 8.64590339 |
| 304 | 29.45 | 11.5308858 | 9.224708639 | 28.272 | 11.02352682 | 8.81882146 |
| 305 | 30.75 | 11.76150351 | 9.409202811 | 29.52 | 11.24399736 | 8.99519789 |
| 306 | 32.05 | 11.99673358 | 9.597386868 | 30.768 | 11.46887731 | 9.17510185 |
| 307 | 33.35 | 12.23666826 | 9.789334605 | 32.016 | 11.69825485 | 9.35860388 |
| 308 | 34.65 | 12.48140162 | 9.985121297 | 33.264 | 11.93221995 | 9.54577596 |
| 309 | 35.95 | 12.73102965 | 10.18482372 | 34.512 | 12.17086435 | 9.73669148 |
| 310 | 37.25 | 12.98565025 | 10.3885202 | 35.76 | 12.41428164 | 9.93142531 |
| 311 | 38.55 | 13.24536325 | 10.5962906 | 37.008 | 12.66256727 | 10.1300538 |
| 312 | 39.85 | 13.51027052 | 10.80821641 | 38.256 | 12.91581861 | 10.3326549 |

|  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
| 313 | 41.15 | 13.78047593 | 11.02438074 | 39.504 | 13.17413499 | 10.539308 |
| 314 | 42.45 | 14.05608545 | 11.24486836 | 40.752 | 13.43761769 | 10.7500941 |
| 315 | 43.75 | 14.33720715 | 11.46976572 | 42 | 13.70637004 | 10.965096 |
| 316 | 45.05 | 14.6239513 | 11.69916104 | 43.248 | 13.98049744 | 11.184398 |
| 317 | 46.35 | 14.91643032 | 11.93314426 | 44.496 | 14.26010739 | 11.4080859 |
| 318 | 47.65 | 15.21475893 | 12.17180714 | 45.744 | 14.54530954 | 11.6362476 |
| 319 | 48.95 | 15.51905411 | 12.41524329 | 46.992 | 14.83621573 | 11.8689726 |
| 320 | 50.45 | 15.82943519 | 12.66354815 | 48.432 | 15.13294004 | 12.106352 |
| 321 | 51.95 | 16.14602389 | 12.91681912 | 49.872 | 15.43559884 | 12.3484791 |
| 322 | 53.45 | 16.46894437 | 13.1751555 | 51.312 | 15.74431082 | 12.5954487 |
| 323 | 54.95 | 16.79832326 | 13.43865861 | 52.752 | 16.05919704 | 12.8473576 |
| 324 | 56.45 | 17.13428973 | 13.70743178 | 54.192 | 16.38038098 | 13.1043048 |
| 325 | 57.95 | 17.47697552 | 13.98158042 | 55.632 | 16.7079886 | 13.3663909 |
| 326 | 59.45 | 17.82651503 | 14.26121202 | 57.072 | 17.04214837 | 13.6337187 |
| 327 | 60.95 | 18.18304533 | 14.54643626 | 58.512 | 17.38299134 | 13.9063931 |
| 328 | 62.45 | 18.54670624 | 14.83736499 | 59.952 | 17.73065116 | 14.1845209 |
| 329 | 63.95 | 18.91764036 | 15.13411229 | 61.392 | 18.08526419 | 14.4682113 |
| 330 | 65.45 | 19.29599317 | 15.43679454 | 62.832 | 18.44696947 | 14.7575756 |

## Appendix 3. In situ Measured Soil Saturated Hydraulic conductivity

| Ksat MEASUREMENT |  |  |  |  |
|---|---|---|---|---|
| Constant-head well permeameter technique |  |  |  |  |
| Date | Site | Soil depth | $K_{sat}$ (mm/h) | $K_{sat}$ (cm/hr) |
| 3/16/2018 | 1 | 0-20cm | 75.88 | 7.587825 |
| 3/16/2018 | 1 | 20-40cm | 2.00 | 0.200264 |
| 3/16/2018 | 2 | 0-20cm | 0.018 | 0.0018 |
| 3/16/2018 | 2 | 20-40cm | 19.43 | 1.9432 |
| 3/13/2018 | 3 | 0-20cm | 18.31 | 1.831 |
| 3/13/2018 | 3 | 20-40cm | 4.91 | 0.491 |
| 3/13/2018 | 3 | 40-60cm | 8.13 | 0.813 |
| 3/15/2018 | 4 | 0-20cm | 23.060 | 2.306 |
| 3/15/2018 | 4 | 20-40cm | 6.460 | 0.646 |
| 3/15/2018 | 4 | 40-60cm | 5.440 | 0.544 |
| 3/19/2018 | 5 | 0-20cm | 7.98 | 0.798 |
| 3/19/2018 | 5 | 20-40cm | 13.9 | 1.39 |
| 3/19/2018 | 5 | 40-60cm | 1.86 | 0.186 |
| 3/15/2018 | 6 | 0-20cm | 45.68 | 4.568 |
| 3/15/2018 | 6 | 20-40cm | 15.97 | 1.597 |

|  |  |  |  |  |
|---|---|---|---|---|
| 3/15/2018 | 6 | 40-60cm | 4.35 | 0.435 |
| 3/19/2018 | 7 | 0-20cm | 46.57 | 4.657 |
| 3/19/2018 | 7 | 20-40cm | 16 | 1.6 |
| 3/19/2018 | 7 | 40-60cm | 2.78 | 0.278 |
| 3/19/2018 | 8 | 0-20cm | 23.06 | 2.306 |
| 3/19/2018 | 8 | 20-40cm | 3.05 | 0.305 |
| 3/19/2018 | 8 | 40-60cm | 2.33 | 0.233 |

## Appendix 4. Sample Measured Volumetric soil water content data

| Area closure with engineering structures |  |  |  |  |  |
|---|---|---|---|---|---|
| θ at Different Profile Depths ($m^3m^{-3}$) |  |  |  |  |  |
| Date | $\theta_{100}$ | $\theta_{200}$ | $\theta_{300}$ | $\theta_{400}$ | $\theta_P$ ($m^3m^{-3}$) |
| 8/22/2017 | 0.131 | 0.257 | 0.328 | 0.401 | 0.279 |
| 8/23/2017 | 0.096 | 0.196 | 0.324 | 0.379 | 0.249 |
| 8/24/2017 | 0.105 | 0.204 | 0.335 | 0.385 | 0.257 |
| 8/25/2017 | 0.099 | 0.203 | 0.332 | 0.376 | 0.252 |
| 8/26/2017 | 0.111 | 0.209 | 0.333 | 0.388 | 0.260 |
| 8/27/2017 | 0.101 | 0.206 | 0.344 | 0.397 | 0.262 |
| 8/28/2017 | 0.132 | 0.231 | 0.346 | 0.390 | 0.274 |
| 8/29/2017 | 0.124 | 0.230 | 0.338 | 0.376 | 0.267 |
| 8/30/2017 | 0.143 | 0.250 | 0.330 | 0.391 | 0.278 |
| 8/31/2017 | 0.164 | 0.245 | 0.318 | 0.355 | 0.270 |
| 9/1/2017 | 0.146 | 0.251 | 0.293 | 0.363 | 0.263 |
| 9/2/2017 | 0.138 | 0.240 | 0.329 | 0.424 | 0.282 |
| 9/3/2017 | 0.129 | 0.240 | 0.323 | 0.410 | 0.275 |
| 9/4/2017 | 0.141 | 0.232 | 0.323 | 0.399 | 0.274 |

| | | | | | |
|---|---|---|---|---|---|
| 9/5/2017 | 0.138 | 0.243 | 0.332 | 0.409 | 0.280 |
| 9/6/2017 | 0.141 | 0.258 | 0.330 | 0.387 | 0.279 |
| 9/7/2017 | 0.135 | 0.246 | 0.334 | 0.393 | 0.277 |
| 9/8/2017 | 0.137 | 0.242 | 0.341 | 0.413 | 0.283 |
| 9/9/2017 | 0.132 | 0.241 | 0.337 | 0.419 | 0.282 |
| 9/10/2017 | 0.125 | 0.242 | 0.337 | 0.392 | 0.274 |
| 9/11/2017 | 0.128 | 0.245 | 0.338 | 0.396 | 0.277 |
| 9/12/2017 | 0.142 | 0.245 | 0.330 | 0.421 | 0.284 |
| 9/13/2017 | 0.147 | 0.242 | 0.351 | 0.409 | 0.287 |
| 9/14/2017 | 0.146 | 0.249 | 0.361 | 0.407 | 0.290 |
| 9/15/2017 | 0.144 | 0.253 | 0.339 | 0.423 | 0.289 |
| 9/16/2017 | 0.138 | 0.247 | 0.352 | 0.361 | 0.274 |
| 9/17/2017 | 0.148 | 0.265 | 0.329 | 0.388 | 0.282 |
| 9/18/2017 | 0.144 | 0.266 | 0.334 | 0.390 | 0.283 |
| 9/19/2017 | 0.148 | 0.246 | 0.309 | 0.384 | 0.272 |
| 9/20/2017 | 0.155 | 0.261 | 0.346 | 0.417 | 0.294 |
| 9/21/2017 | 0.157 | 0.277 | 0.358 | 0.429 | 0.305 |
| 9/22/2017 | 0.156 | 0.284 | 0.351 | 0.444 | 0.309 |
| 9/23/2017 | 0.158 | 0.242 | 0.348 | 0.422 | 0.292 |
| 9/24/2017 | 0.160 | 0.226 | 0.350 | 0.425 | 0.290 |
| 9/25/2017 | 0.143 | 0.216 | 0.343 | 0.390 | 0.273 |
| 9/26/2017 | 0.150 | 0.256 | 0.334 | 0.417 | 0.289 |
| 9/27/2017 | 0.148 | 0.241 | 0.320 | 0.361 | 0.267 |
| 9/28/2017 | 0.149 | 0.236 | 0.325 | 0.364 | 0.268 |
| 9/29/2017 | 0.152 | 0.227 | 0.320 | 0.364 | 0.266 |
| 9/30/2017 | 0.153 | 0.253 | 0.339 | 0.357 | 0.275 |
| 10/1/2017 | 0.144 | 0.252 | 0.360 | 0.373 | 0.282 |

## Appendix 5. Sample Surveyed Ground water level data in wet and dry season

| | | | Geographic setting | | | | SWL | |
|---|---|---|---|---|---|---|---|---|
| No. | Kebelle | Got | X | Y | Z | depth | April/ Dry | July/wet |
| 1 | Gombat | Zenbet | 334070 | 1293515 | 1862 | 14 | 10.5 | 7 |
| 2 | Gombat | Zenbet | 334101 | 1293410 | 1868 | 12.5 | 10 | 6 |
| 3 | Gombat | Zenbet | 334116 | 1293398 | 1868 | 14.5 | 12.5 | 5.5 |
| 4 | Gombat | Zenbet | 334212 | 1293279 | 1861 | 6.5 | 5 | 4 |
| 5 | Gombat | Jint | 334192 | 1293125 | 1862 | 6 | 5 | 2.5 |
| 6 | Gombat | Jint | 334160 | 1292946 | 1862 | 9 | 7.5 | 3 |
| 7 | Gombat | Jint | 334422 | 1292883 | 1872 | 15 | 12.5 | 4 |
| 8 | Gombat | Jint | 334465 | 1292957 | 1866 | 11 | 10 | 4 |
| 9 | Gombat | Jibat | 334505 | 1292948 | 1866 | 11.5 | 10.3 | 5 |
| 10 | D/Tsion | Quraz | 335762 | 1288532 | 1978 | 13 | 12 | 5 |
| 11 | D/Tsion | Quraz | 335859 | 1288619 | 1986 | 11 | 9 | 4.5 |
| 12 | D/Tsion | Quraz | 335772 | 1288648 | 1983 | 9 | 7 | 3.5 |

|  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
| 13 | Laguna | Kecha | 335859 | 1289119 | 1976 | 15 | 12.5 | 6 |
| 14 | Laguna | Kecha | 335846 | 1289098 | 1995 | 10 | 9 | 7 |
| 15 | Laguna | Kecha | 336161 | 1289054 | 1970 | 7 | 4 | 0.5 |
| 16 | Laguna | Kecha | 336228 | 1289091 | 1976 | 6 | 4 | 1.5 |
| 17 | Laguna | _ | 336566 | 1288509 | 1989 | 6 | 3 | 0 |
| 18 | Laguna | _ | 336552 | 1288493 | 1997 | 6 | 3 | 1 |
| 19 | A.Gerima | kecha | 336057 | 1290597 | 1901 | 7 | 5 | 3 |
| 20 | A.Gerima | kecha | 336020 | 1290644 | 1925 | 7 | 5 | 3.5 |

## List of Plates

Plate i. Mixed soil and water conservation structures in CL (Aba Gerima)

Plate ii. Damaged WSM structures in CLs (terraces and trenches)

**Plate iii. Emerging of Soil erosion and gully formation processes in Aba Gerima**

**Plate iiii. Area closure (Rehabilitated land)**

**Plate iv. Stream discharge guaging station in Yidemo stream _Aba Gerima**