IMPACT OF LAND MANAGEMENT PRACTICES ON GROUNDWATER RECHARGE: CASE OF EDO-WATERSHED IN THE ETHIOPIAN RIFT VALLEY BASIN

MASTER OF SCIENCE THESIS

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HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

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We, the undersigned, members of the Board of Examiners of the final open defense by Ashenafi Dora have read and evaluated his thesis entitled ‘’ **Impact of land management practices on groundwater recharge: case of Edo-watershed in the Ethiopian Rift Valley Basin”**, and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement for the degree Masters.

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DEDICATION

This thesis is dedicated to my mother, for her never-ending love, support, and encouragement.

DECLARATION

I, Ashenafi Dora, declare that this MSc. The thesis is my original work and has not been presented for a degree in any other university, and all sources of materials used for this thesis have been duly acknowledged.

Name: Ashenafi Dora

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This MSc Speciality thesis has been submitted for examination with my approval as thesis advisors.

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STATEMENT OF THE AUTHOR

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LISTS OF ABBREVIATIONS AND ACRONYMS

AET	Actual evapotranspiration
AGP	Agricultural Growth Program
BCM	Billion-Meter Cube
BL	Bare land
C	Hydraulic capacity
CEC	Cation exchange capacity
CL	Conserved land
CMB	chloride mass balance
CSA:	Central Statistical Agency
DEM	Digital Elevation Model
1D	One dimensional
2D	Two dimensional
3D	Three dimensional
EPA	Environmental Protection Agency
ET_o	Reference Evapotranspiration
FAO	Food and Agriculture Organization
FC	Field capacity
FGDS	Focus Group Discussion
GMC	Gravimetric moisture content
GIS	Geographic Information System
GPS	Global Positioning System
h	Hydraulic head
hh	Household
Ha	Hectare
HU	Hawassa University
K	Hydraulic conductivity
Km^2	Kilometer square
K_h	Hydraulic conductivity at a matric potential
km^3	Kilometer Cube

Kp_a	Kilopascal
LULC	Land Use Land Cover
MBE	Mean bias error
MCM	Million Cubic Meter
Mm	millimeter
Mm^3	Million-meter cube
MW	Megawatt
n	Pore size distribution index
n.d	non-dated
NMAE	National Meteorological Agency of Ethiopia
P	Precipitation (rainfall)
PET	Potential Evapotranspiration
PTF	Pedo transfer function
PWP	Permanent wilting point
RMSE	Root Mean Square Error
R	Recharge
R^2	Coefficient of determination
S	Sink term
SCS	Soil Conservation Service
SNNPR	South Nation and Nationality People Region
SWAT	Soil Water Assessment Tool
SWB	soil water balance
SWC	Soil water content
SWD	Soil water dynamics
Tmin:	Minimum temperature
Tmax:	Maximum temperature
US	united state
VGM:	Van Genuchten – Mualem
WWAO	Woreda Agriculture and Natural Resource Office
Z_r	Rooting depth (m)

ABSTRACT

Proper water resource planning requires an understanding of the availability and use of ground water. But, there is lack of information in the Edo watershed on groundwater availability, rate of recharge, and there is limited information on the impact of land management on groundwater. In line with this, the objective of this study was to determine the impact of land management practices on groundwater recharge and soil water dynamics on conserved land and bare land at the Edo watershed in Wondogenet. In this study, the Hydrus-1D model and water table fluctuation methods were used to estimate groundwater recharge. Hydrus -1D model is the Richards-based vadose zone hydrological model. The meteorological, and soil hydraulic data were used as input data to the Hydrus-1D model. Soil hydraulic parameters were estimated from easily measured soil physical properties using ROSETTA-derived prior information about soil hydraulic parameters. Water table data from twenty-five wells was used to estimate the recharge. The model performance was evaluated by comparing the observed and simulated soil water content values both on conserved land and bare land in the study area. The high value of R^2 *0.997 and a low value of ME (0.049) for calibration and a high value of* R^2 *0.99 for Conserved land and 0.93 for bare land and low (RMSE of 0.23-0.28, MEB of 0.057-0.23) values during validation showed that there was a good agreement between the observed and simulated soil water content. The overall evaluation according to the common performance evaluation techniques revealed that the observed and simulated soil water content in conserved land was higher compared to those in bare land. From the Hydrus -1D, the long-term average annual groundwater recharge was 3,976,409.32 m3 or 297.8896mm, which is 26.92 % of average annual rainfall, and the water table fluctuation method 257mm, which is 23.23% of average annual rain fall. From the result, it can conclude the conserved land was better than bare land due to storing more water. The current observation showed that good land management practices were useful to sustain the water resources in the watershed.*

Keywords: *Edo watershed, Hydrus-1D, Land Management Practices, Groundwater Recharge***,** *and Soil Water Dynamics***.**

1. INTRODUCTION

1.1. Background of Study

Groundwater is a vital natural resource and a main component of the hydrologic cycle. In the past, water was often used with no regard to the impacts on future water availability and quality. This mismanagement has led to increasing threats of water scarcity for the 1.5 billion people worldwide rely on groundwater as their main source of freshwater (Moubarak, 2013). Groundwater is the world’s most extracted and fresh raw material with withdrawal rates currently estimated to be 1000 cubic kilometers per year (Margat & Gun, 2013). Over the world, About 70% of groundwater withdrawn is used for agriculture, and 50% for all drinking water worldwide (Smith et al., 2016).

Groundwater is increasing as supplant of surface water in many areas of the world as the primary and preferred source of water for all types of use (Adugna, 2015). Sustainable use and management of this crucial resource highly depend on the amount of water that replenishes groundwater aquifers; this is often simply referred to as recharge. Aquifer recharge is water that moves from the land surface or unsaturated zone into the saturated zone. The aquifer recharge rate can be the most difficult component to measure when evaluating groundwater sources. Aquifer systems are the appropriate spatial units for assessing and managing the groundwater resources (Jiří Šimůnek et al., 2016).

Groundwater recharge is the process by which water percolates down the soil profiles and reaches the water table, either by natural or artificial methods (Scanlon & Cook, 2002). Reliable estimation of groundwater recharge rate is crucial for the assessment of groundwater resource potential in Africa (Chung., 2016). Groundwater forms the basis of water supplies across much of Africa and its development is rising as the demand for secure water increases.

Quantifying the rate of groundwater recharge is fundamental to assessing current water security and helping forecast future changes (Taylor et al., 2013, Gleeson et al.,2020). Rapid population growth and development in many African countries, together with the increasing availability of solar-powered pumps (Wu et al ., 2017) have now focused attention on the increased development of groundwater for irrigation and piped drinking-water supplies (Gaye and Tindimugaya 2019, Cobbing 2020). Quantifying the scale of groundwater recharge is required to characterize the resilience of groundwater supplies to both increased abstraction and climate change.

To maintain water sustainability, effective methods and mechanisms should be used. In now a day, the hydrological models are good to represent the hydrological characteristics (Surur, 2010). Hydrologic modeling and water resources management studies are closely related to the spatial processes of the hydrologic cycle. The importance of the unsaturated zone as an integral part of the hydrological cycle has long been recognized. The vadose zone plays an inextricable role in many aspects of hydrology, including infiltration, soil moisture storage, evaporation, plant water uptake, groundwater recharge, runoff, and erosion (Applications et al., 1998).

Hydrus-1D is software to analyze one-dimensional flow in partially saturated flow. It is one of the advanced lumped/distributed models applied in the simulation of water flow, moisture distribution, and solutes transport in the unsaturated zone (between the soil surface and water table). Interest in the unsaturated zone has dramatically increased in recent years because of growing concern that the quality of the subsurface environment is being adversely affected by agricultural, industrial, and municipal activities (Simůnek et al., 2009). To achieve these objectives, knowledge of the available ground and surface water resources and the capacity to use them; the conservation of the surface runoff and groundwater recharge, and the impact of climate change as well are needed to be taken into consideration.

As in many parts of the world, the population in Ethiopia increased rapidly in the last century. This eventually resulted in large-scale land-use changes, deforestation, overgrazing, expansion of crop land to marginal and steeply sloping areas, poor soil management practices, and unsustainable use of natural resources (Tesfahunegn et al., 2012). These practices reduce rainwater infiltration resulting in more surface runoff and water erosion. This leads to exhaustion of the soil, decreasing soil quality, and eventually a decline in soil productivity (Bewket, 2003). Small-scale farmers will be seriously affected by long-term consequences on land productivity.

This is experienced with unforeseen bad weather conditions and improper management of land and water resources in the region. The traditional management of land-based resources, coupled with a growing interest and reliance on various products and services from those resources poses a challenge for managing the natural resources (Adem, 2020).

Natural effects are such as climate changes are only over a long period, whereas the human effects are immediate and often direct. Out of the human factors, population growth is the most important in Ethiopia (Berehanu et al., 2015), as it is common in developing countries. Ethiopia is one of the most populous countries in Africa with a population of 70 million people and an annual growth rate of 2.6 million people (CSA, 2008). 85 % of the population of lives in rural areas and directly depends on the land for its livelihood. This means the demand for land is increasing as the population increases.

Agriculture serves as a livelihood and ensures the food security of the people in the area; therefore studying the availability of water resources is quite essential. However, unless the available water resources are utilized with a balanced approach to the supply and demand and with careful consideration of sustainability, satisfying the needs of current and future generations will remain under question. Nevertheless, for planning the sustainable use of water resources, the impact of land management practices has to be considered.

The Edo watershed has been confronted with several land use and land management practice dynamics in the previous decades and the amount of recharge depends on it. Therefore to estimate and understand the impact of land use and land management practices on groundwater recharge, it is also important to accurately assess the type and direction of changes occurring within the watershed. The available water in the watershed and its recharge rate and the impact of land management practices studies as well needs to be conducted. It will be a better implication for the people in the watershed to use it for their benefit based on the results obtained from the study.

1.2. Statement of the Problem

Groundwater is a precious resource to a limited extent. For the good use of it, proper prospecting, management, and assessment are required. Due to the increasing number of people living in cities and rural areas as a result of the increase in world population; it becomes necessary to scout for other alternative sources of fresh water (Adem, 2018). Understanding and quantifying recharge processes are the prerequisites for any analysis of resource sustainability. The first important step in recharge analysis is to consider the scale of the study area since the approach and methods of quantification are directly influenced by it (Neven Kresic, 2009).

Since the groundwater occurs out of our sight, deep in the subsurface, there is no direct method to facilitate observation of water below the surface. Its presence or absence can only be inferred indirectly by studying the groundwater occurrence and distribution controlling parameters. So, to ensure the wise use of groundwater, a systematic evaluation of groundwater is required (Gintamo, n.d.). In rural areas, the water demand is become increased due to different climatic factors and the influence of human activities.

The major problems of the study area are the day-to-day change of land use and pressure of population increases and changing of rural land to urban land, due to this deforestation is a day-to-day activity of the people living in the watershed. The watershed is also facing high erosion by the effects of degradation of land which aggravates the land-use change of the watershed. The land-use change cause different problem in existing hydrological conditions. Changes in land use type of certain areas like increasing the percentage of impervious area will increase the volume of surface run off decrease time of concentration which makes several distractions by generating a higher amount of runoff as well as decrease the amount of water percolated into the ground that in turn decrease amount of water to be recharged into the ground finally imbalances over all hydrological condition of the catchment.

It should be assessed deeply to know how land uses affect the different hydrological processes. Even though there are different land-use practices in the study area there is a limitation to applying for estimation of the recharge of shallow groundwater and there is a lack of information on groundwater availability and rate of recharge and thus rates of sustainable withdrawals and also there is limited information on land use practices. Therefore, evaluation of the groundwater reserve and the land use requirement is a primary and essential action to be performed prior to any development activity. Thus, it is essential to conduct a study to find out information regarding the amount of recharge of shallow groundwater and the impacts of land management practices on the watershed.

1.3. The Objective of the Thesis

1.3.1. General objective

The main objective of the study was to assess the impact of land management practices on groundwater recharge of the Edo watershed using the Hydrus-1D model, and water table fluctuation method.

1.3.2. Specific objectives

To achieve the above main objective, the following sub-objectives are included:

- To evaluate the applicability of the Hydrus-1D model in the study area.
- To evaluate the total amount of groundwater recharges using the Hydrus-1D model, and water table fluctuation method.
- To evaluate the effect of conservation practices on soil water dynamics.
- To assess the impact of conservation structures on groundwater recharge.

1.4. Research Questions

- ✓ Is the Hydrus1-D model applicable in the Edo watershed?
- ✓ How can the amount of groundwater recharges be evaluated and analyzed by the Hydrus-1D, and water table fluctuation method?
- ✓ What are the effects of conservation practices on soil water dynamics compared to bare land?
- ✓ What is the impact of conservation structures on groundwater recharge?

1.5. Significance of the Study

Land use and land management practice have significant impacts on groundwater recharge, socioeconomic, and environmental systems. However, to assess the effects of land use and land management practice change on groundwater recharge, it is important to have an understanding of the land use and land management practice patterns and the hydrological processes of the watershed. Understanding the types and impacts of land use and land management practice change is an essential indicator for water resource base analysis and the development of effective and appropriate response strategies for sustainable management of groundwater resources in the country in general and in the study area in particular.

Moreover, the study presented a method to quantify land use and land management practice change and their impact on groundwater recharge. This has been achieved by using the Richards-based soil water balance model Hydrus-1D and metrological time series from the analog station. The water resource planner will benefit by using the result of this study as input and consequently, the population at large will benefit from the policy, which is the ultimate end. In addition, the paper can be used as an input for other researchers to look at the research gaps like the quality aspects. More specifically, the finding of this study may help to:

- Provide information on the groundwater potential, create awareness for the farmer related to land-use change on groundwater, and enable the farmer to use water for irrigation.
- In rural areas, groundwater well-digging projects will benefit from getting information on the recharge.
- It may show the impact of land-use change on the hydrological regime.
- It helps to develop and manage sustainable land management practices and water resources for the communities.

1.6. Scope of the Study

The scope of this study was limited as follows as.

- The study was limited to an unconfined aquifer with a shallow water table of the watershed.
- The study included only the Hydrus-1D model and the water table fluctuation method for recharge estimation.
- The study gives focuses on the estimation of recharge amount only from rainfall.
- The analysis is limited to the quantity of groundwater recharge

1.7. Organization of the Thesis

This paper is organized into five different chapters dealing with different topics. Chapter one elaborates on the introduction part of the study including the background, problem statement, objectives, significance, and scope of the study. Chapter two presents a literature review, which encompasses definition, different land management practices and its contributions to groundwater recharge and soil moisture dynamics. Chapter three deals with the research methodology which includes both qualitative and quantitative approaches to the study. In chapter four the results and discussions are presented and finally, Chapter five presents the summary and conclusions.

2. REVIEW OF RELATED LITERATURE

2.1. Concept of Land Management Practices and Groundwater Globally

The broad concept of land management practices refers to activities on the ground that uses appropriate technologies in the respective land-use system for the improvement of the productive capacity of the land. This includes activities such as the use of physical SWC measures, soil fertility management practices, controlled grazing, agricultural water management, forestry, and agro forestry practices It incorporates the adoption of land use systems through appropriate management practices that enable land users to maximize the economic and social benefits from the land while maintaining the ecological functions of the land resources (FAO, 2009).

It can be seen from economic, social, institutional, political, and ecological dimensions. Thus, land management practices emphasize finding economically viable, socially acceptable, and ecologically sound solutions at a local, regional, national and global level, which could promote participatory land management practices to deal with land degradation (FAO, 2009). Land management is a complex process, which is not only the result of the will or act of land users. Its problems and achievements go beyond the household's domain of operation to include actors in the surrounding environment (Assefa, 2007).

It combines technologies, policies, and activities that are aimed at integrating socio-economic principles with environmental concerns so as simultaneously maintain production, reduce the level of risk, protect the potential of natural resources and prevent soil and water degradation, be economically viable and be socially acceptable (Senait, 2002). Groundwater is an appreciated natural resource for the dependable and economic provision of better quality water supply in many regions of the Earth. There is only 2.8% of the total available water on the Earth is categorized as fresh water, with 97% of which being groundwater (Sekhri, 2013).

Groundwater is important for both human consumption and the preservation of the ecological value of many areas worldwide. Groundwater has emerged as a poverty reduction tool in many developing countries because it can be cost-effectively and uncomplicatedly distributed to poor rural areas than surface water. Approximately 34% of the overall global annual water supply is groundwater, with the surface water resource alone being insufficient to fulfill the ever-increasing population demand for water. In addition, more than 50% of the global population relies on groundwater resources to cater to their basic day-to-day water needs, while the majority of farmers depend on groundwater to cater to their wellbeing and contribute to the food security of so many others (Beekman & Xu, 2003).

Groundwater also represents approximately 43% of all water used in irrigation globally. It is preferred the most because it is usually protected from the hazards of pollution; hence it requires less treatment when compared to surface water. Groundwater supplies are, nevertheless, declining, with a projected 20% of the world's aquifers presently over-exploited. Approximately 40% of global groundwater abstraction occurs in arid and semi-arid regions and yet the shortage of rain in these regions implies that only 2% of groundwater recharge takes place there (Wada et al. 2010). Therefore, understanding the nature and occurrence of these resources is imperative for their sustainable utilization and management purpose.

Groundwater comprises water that exists beneath the land surface, held within openings or pores of soils and geological formations. According to most classical definitions, this term refers exclusively to water occurring at or beneath a surface, known as the water table. Below the water table is a region known as the saturated zone, pores are filled with water. Trimmer (2000) defines groundwater as water that naturally occurs in porous rock materials underground.

2.2. Groundwater Recharge Amount in Ethiopia

Groundwater recharge is the amount of moisture that will get into the saturated zone until it eventually reaches the permanent water table which can raise the water table by a measurable amount (Kumar, 2012; Sophocleous, 2005). Recharge quantification is associated with significant technical problems, data deficiencies, and results from uncertainty because of the wide spatial and temporal variability of rainfall and runoff events, especially in the more arid regions, the widespread lack of lateral uniformity in soil profiles, and hydrogeological conditions (Gemitzi et al., 2017).

The selection of method(s) of natural recharge estimation depends on the purpose that may vary from groundwater assessment for management decisions, augmenting groundwater recharge, to identifying better sites for disposal of hazardous waste materials (Sophocleous, 2005).

The recharge measurement methods could be direct, Darcy's approaches, environmental tracers, water balance; water table fluctuation methods, and numerical models. Estimating the recharge rate accurately is the most challenging exercise in hydrogeology, particularly in arid and semi-arid parts of Ethiopia. On the other hand, the recharge and discharge conditions of an area are controlled by several factors such as; climate, topography, drainage, geologic framework, soil condition, land use/land cover, and vegetation (Kebede, 2013).

The main source of recharge in Ethiopia is rainfall, supplemented by channel losses from large rivers draining into permeable and fractured hydro-stratigraphic units. The Recharge rate in Ethiopia varies between 0 to 400 mm/year. The highest recharge corresponds to high rainfall areas in southwest Ethiopia and the north-central plateau where annual rainfall is high, and low recharge is recorded around Afar (Alemayehu, 2006). Kebede et al.'s (2010) study show that the principal recharge pathway in the highlands of Ethiopia is recharge taken through fractures from heavy rainfall fractions rather than recharge taking place from soil moisture excess.

2.3. Groundwater Potential in Ethiopia

"As compared to surface water resources, Ethiopia has lower groundwater potential. However, by many countries' standards, the total exploitable groundwater potential is high" (Yilma & Awulachew, 2009). The peculiar feature of Ethiopia is the difficulty in obtaining productive aquifers which are characterized by the wide heterogeneity of geology, topography, and environmental conditions(Kebede, 2013; Seleshi et al., 2014).

Groundwater potential in Ethiopia is influenced by complex geological formations and the diversity of the topography, climate, soil, and the variability of these factors strongly governs the quantity and quality of the groundwater found in different parts of the country (Gebregziabher et al., 2012).

Moreover, the spatial and temporal variability of the water resources is highly characterized by the multi-weather systems rainfall of the country (Žáček et al., 2014). The country has a geological condition that provides usable groundwater and provides good transmission of rainfall to feed aquifers, which produce springs and feed perennial rivers, and over the last two decades, groundwater development has become a new issue in Ethiopia (Alemayehu, 2006).

Even though it needs further detailed investigation, based on the current scanty knowledge, the country has about 124.4 (BCM) river water, 70 BCM lake water, and 30 BCM groundwater resources and it has the potential to develop 3.8 million ha of irrigation and 45,000 MW hydropower productions (Žáček et al., 2014). Awulachew & Merrey, (2007) revealed an estimate of 2.6 - 6.5 Bm^3 of groundwater potential, and the majority of the rural Ethiopian water supply relies on groundwater.

2.4. Land Use and Land Management Practices in Ethiopia

In Ethiopia, the land is used to grow crops, trees, and animals for food, as building sites for houses and roads, or for recreational purposes. Most of the land in the country is being used by smallholders who farm for subsistence. Land management in Ethiopia has evolved into various farming systems with different levels of intensification (Wegayehu, 2006). In the same way, Ayalneh (2002) points out that several SWC techniques have been employed by farmers, most of which have their origin in the traditional knowledge but adapted to the present environmental and social circumstances through experiments through generations.

Gashaw et al., (2020) classified the land management practices that have been applied in Ethiopia into two broad categories: indigenous and introduced, with different degrees of acceptability, areal coverage, and benefits. The acceptance and implementation of these management practices depend on the desire and willingness of farmers, which in turn request continuous and effective deeds from agricultural experts and researchers. It is not easy, to put common criteria to categorize land management practices into indigenous and introduced. As a result, this categorization is done based on the direct purposes of the management techniques that farmers apply on their farmlands in the study area (Wolka et al., 2015).

2.5. Factors Affecting Groundwater Storage

Groundwater storage depends on aquifer parameters, rate of water movement, and recharge of the aquifers. Groundwater movement like surface water is affected by the nature of slope or elevation. Thomas (2003) states that groundwater moves from higher elevations to lower elevations and from the location of higher pressure to the location of lower pressure. The Science of groundwater movement is described as groundwater hydraulics. In groundwater hydraulic, it is the hydraulic head that determines groundwater movement.

Groundwater movement is rapid in gravels and sands and slows in clay or tiny rock features. The ability of a rock layer or geologic formation to move water is called hydraulic conductivity. Factors determining groundwater movement and storage in any form of an aquifer are hydraulic properties or dimensions of aquifers, type of aquifer confined or unconfined, and climate that is in terms of rainfall recharge.

In another development, Buddemeir and Schloss (2000) pointed out that groundwater development potential yield depends on aquifer characteristics such as hydraulic conductivity, aquifer thickness, storability, aerial extent, groundwater levels, available drawdown, and recharge. This indicates that the nature of the soil, geology; climate, and properties of an aquifer are the major factors controlling the movement and storage of groundwater in any part of the world. Groundwater recharge and storage to the shallow unconfined aquifer is complex and is dependent upon the occurrence, intensity, and duration of precipitation, temperature, humidity, wind velocity as well as character and thickness of soil and rock above the water table and the surface topography, vegetation and land use. Climatic elements and geophysical factors are not the only factors that determine groundwater movement and storage. Groundwater storage depends not only on precipitation but also on meteorological conditions, as well as on soil type, soil-moisture status, vegetation cover and condition, slope, cultivation practices, and most of all, evapotranspiration, which is a function of the other factors.

2.6. One Dimensional Model

Nowadays, understanding groundwater and land management concerning the soil-water-plant atmosphere system allowed the development of models for soil moisture in the unsaturated zone. Yet, because of the numerous models, it is obvious that no universal model exists that can be applied in all situations, but rather that each model has its weaknesses and strengths (Forkutsa, 2006). Bastiaanssen et al., (2004) emphasized that model selection criteria should follow the objectives of the study. One-dimensional models have proven their validity not only with laboratory experiments with uniform soil cores but also in the field in the case of deep groundwater tables (Kelleners et al., 2005).

One-dimensional models have proven their validity not only with laboratory experiments with uniform soil cores, but also in the field in the case of deep ground water tables (Kelleners et al., 2005). One–dimensional models were used successfully in the case of vertically heterogeneous soils but only when the soil hydraulic properties were known for every soil layer. Despite the obvious advantages of one-dimensional (1-D) models, which mainly lie in their simplicity, concluded that if the soil profile is not homogeneous horizontally and boundary conditions are not uniform, a 1-D model may fail to mimic reality (Van Dam et al., 2004).

In case a lateral water flow is prevailing and not a vertical flow, it is recommended to apply 2-D and 3-D models instead of the 1D model. If there is no dominant lateral flow, 1-D models are preferable (Van Dam et al., 2005). One–dimensional models are simpler than 2-D and 3-D models. Yet in unsaturated soils, the water flow is predominantly vertical, i.e., one-dimensional (Hillel, 2003); (Meiwirth .,2004). One–dimensional models nevertheless solve the Richards equation accurately and efficiently, (Scanlon & Cook, 2002). Among many developed models that are based on the Richards equation, the Hydrus-1D model (J.Simunek et al., 1998) was selected and applied in the current research. The Hydrus-1D model includes relatively easy and useful tools to simulate soil water content, and on the other hand predicts soil hydraulic conductivity, root water uptake, and bottom flux (recharge).

2.7. Hydrus-1D Model

The Hydrus-1D is one of the most widely used numerical models for simulating water flow and solute transport in variably saturated soils and groundwater. This model was developed by the U.S. Salinity Laboratory, U.S. Department of Agriculture, Agriculture Research Service (Simunek et al., 1998).

The Hydrus-1D model is an important means to simulate the complex soil moisture movement. The transient water flow within the unsaturated soil profile was simulated by numerically solving the Richards equation with the Hydrus-1D. The Hydrus-1D model which is based on the Richards equation and simulates one-dimensional water movement in multi-layered variably saturated soil was applied to predict deep percolation and actual evapotranspiration (Jirka Šimůnek & Genuchten, 2008).

The Hydrus-1D software packages can simulate solute, heat, and carbon dioxide transport in variably saturated media assuming either a vertical, horizontal, or generally inclined direction in addition to water flow. This numerical model is widely used to simulate water flow and solute transport in variably saturated soils and groundwater. Hydrus-1D software can be used to simulate such processes as infiltration, evaporation, transpiration, soil water storage, deep drainage, and surface runoff (Šimůnek et al., 2012).

The flow equation incorporates a sink term to account for water uptake by plant roots. The flow equation may also consider dual-porosity type flow in which one fraction of the water content is mobile and another fraction immobile, or dual-permeability type flow involving two mobile regions, one representing the matrix and one the macro pores. The program may be used to analyze water movement in unsaturated, partially saturated, or fully saturated porous media. The flow region may be composed of non-uniform soils. Flow and transport can occur in the vertical, horizontal, or generally inclined direction (Simunek et al., 2005).

In the Hydrus-1D model, the soil water fluxes are calculated by the standard Richards equation. The model has two parts pre-processing and post-processing part. Preprocessing part includes input data such as simulation parameters, time-step parameters, parameters defining the geometry, soil hydraulic properties, initial and boundary conditions, output times, and observation point location. The output data of the model include simulation time, number of iterations in each time step, total cumulative of the number of iterations, flow variations in the upstream border, total cumulative input flow, total cumulative water absorption by root, total cumulative output flow and Matrix Potential (Honar et al., 2011).

Since water movement between the soil surface and water table (unsaturated zone) is dominantly vertical (one–dimensional), Hydrus-1D can be used to study the soil-water dynamics and groundwater recharge (Wongkaew et al., 2018). Several researchers such as (Dickinson et al., 2014; Pfletschinger et al., 2014; Rieckh et al., 2014; Turkeltaub et al., 2014, and Fan et al., 2015); preferred Hydrus-1D and successfully applied it to unsaturated zone groundwater recharge estimation.

2.8. Soil Water Dynamics

Soils play a major role in the water cycle due to their capacity for filtering, and redistributing water between the atmosphere, the groundwater, and the vegetation cover (Blum, 2005). SWC is the amount of water held in the soil at any given time and can be expressed as volumetric and gravimetric water content. Volumetric water content is the volume of water per unit volume of dry soil and the most useful way of expressing water content for developing a water budget.

Gravimetric water content is the mass of water per unit mass of dry soil (Easton., 2016). Soil water, as an important existing form of water resource, has close ties with the field of agriculture, hydrology, and the environment (Liang et al., 2015). Different processes are dependent on the soil's physical and chemical properties and will determine the water movements and its availability in the soil. Those processes are moreover spatially heterogeneous (Müller, 2015).

Soil water is the water held in the process of the unsaturated zone. It is one of the most important soil variables, relative to climatology and hydrology (Houser et al., 1998). Surface and root-zone soil moisture regulate the water budget at the soil-vegetation atmosphere interface. SWC is an important parameter in watershed modeling as well since it partially controls the partitioning of rainfall, infiltration, and surface runoff and thus the hydrodynamic of the river flow at the outlet (Koster et al., 2003).

Stored water in the soil is a dynamic property that changes spatially in response to climate, topography, and soil properties, and temporally as a result of differences between utilization and redistribution via subsurface flow, (Western et al., 1999). Changes in soil water storage can be generalized with a mass balance equation (as a result of the difference between the amount of water added and that which is lost, (Hillel, 2003).

Knowledge of soil moisture water dynamics in the unsaturated soil zone provides valuable information on the temporal and spatial variability of groundwater recharge (Ries et al., 2015). Water dynamics in soil are governed by many factors that change vertically with depth, and temporally in response to climate (Swarowsky et al., 2011).

Water content increases (positive change in storage) when inputs including precipitation or irrigation exceed outputs. Water content decreases (negative change in storage) when outputs such as deep percolation, surface runoff, and evapotranspiration (ET) exceed inputs (O'Geen, 2012).

Understanding soil water dynamics and accurately estimating groundwater recharge are essential steps in achieving efficient and sustainable management of groundwater resources in regions with deep vadose zones. The amount of soil water content at different depths increased following the rainy season and then gradually stabilized. And the intensity and continuity of precipitation events played an important role in soil water changes (Ju et al., 2010).

2.9. Vadose Zone Processes

Vadose zone processes determine the amount of water that percolates through the unsaturated zone to reach the groundwater table. It also affects the pathways of a contamination plume before it reaches aquifers. A wide range of computer programs is available to simulate water and/or heat movement processes in the vadose zone. As described in section 2.2, groundwater recharge may be estimated using different methods such as water table fluctuation methods and water balance-based numerical models (Ligget and Allen, 2010). However, these methods are reported to be unreliable due to imprecision in porosity estimation and overestimation of the 'true' recharge (Loukili et al., 2008; Khire et al., 1997; Gogolev, 2002; Hollaender et al., 2009).

On the other hand, physically-based models can fully describe the natural system using mathematical formulations of the fundamental physical processes. Based on current understanding, the Richards equation for vadose zone water movement is believed to appropriately describe the underlying physical processes. Hydrus-1D is one such software package that uses the above concepts for simulating water and heat movement in the vadose zone (Simunek et al., 2005).

Besides the physical foundation of the model, other reasons for choosing Hydrus-1D for this modeling are listed below.

- ❖ Hydrus-1D has been extensively verified and used by thousands of users around the world, including leading research centers and regulatory agencies (e.g., Pacific Research Center, EPA, Campbell Scientific, US Army Engineer Research and Development Center, and several universities around the world). Complete lists can be found on the Hydrus-1D official website (www.pc-progress.com). Recent applications of Hydrus-1D for recharge calculations can be seen in (Šimůnek et al., 2013).
- ❖ Hydrus-1D represents "the cutting edge" of research developments in unsaturated zone hydrology. It is developed by leading scientists in the field of vadose zone hydrology.
- ❖ Hydrus-1D versions (Simunek et al., 2013,), provide an ideal platform for which objectives of this study, namely evaluating the impact of land management practices on groundwater recharge in the watershed.

2.10. Previous Studies Conducted In the Study Area

Since the Lake Hawassa basin provides many important, different studies had been carried out, but in the case of the Edo watershed there was no specific and separate study exclusively about groundwater recharge, all the studies were undertaken about Lake Hawassa or the country as a whole. The review of previous studies at the Edo watershed is presented in the following paragraphs of which most of the studies are related to assessing the water quality of rural water supply, impact of land-use change on the livelihoods, geochemical monitoring of the lakes district area, and shallow groundwater resource in general senses.

Wondimagegn (n.d) conducted a study on the assessment of land management practices and their contribution to livelihoods at the household level in Edo. In this study, the great emphasis had given to Biological and physical land management practices in the study area. Such as soil bund, stone check dam, traditional ditches, gabion check dam, soil/sandbag check dam, Manure application, mixed cropping, intercropping, crop rotation, and tree planting. Moreover, land management practices should not only be aimed at minimizing soil erosion but should also cover other household objectives, such as the improvement of soil fertility, increase crop production, and improving income in households.

Deneke and Moges et al (2012) again conduct a study on assessing the water quality of rural water supply schemes as a measure of service delivery sustainability: A case study of Wondo Genet district. This study was conducted in the Wondo Genet district, Sidama region to assess the water quality of rural water supply schemes concerning the sustainability of their service delivery. The assessments included sanitary surveillance of water points and water quality analyses.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

Wondo Genet woreda is found in Hawssa zuria in the Sidama region and is one of the agricultural growth program woredas in the region. It is located 270 km south of the capital city of the country and 24 km from the capital city of the region latitude and longitude of 6°45’ N to 7°15’ N and 38°15’ E to 38°45 E respectively with an altitude of 1780 meters above sea level (masl). The area of study was in the Edo watershed. The site receives a mean annual rainfall of 1128mm with minimum and maximum temperatures of 10.7 o_C and 30.2 o_C, respectively. The Woreda has 225.00 Square K_m and it has 13 Kebeles (WANRO, 2019). The livelihood system of the kebele is based on crop production and livestock and agriculture is the main source of income for the population and is characterized by cash crop (chat) production and “Enset” as a major livelihood strategy. Trade and services activities are going on at the center of the Woreda. “Enset” is mainly used for household consumption purposes the major livestock managed in the area include cattle, cows, horses, donkeys, sheep, chickens, and goats (WWAO, 2019). Manual water-lifting devices are widely used in the kebele. Even though the potential is very poor, especially around February- May, Groundwater is the main water source used in some parts of a watershed for small-scale irrigation and domestic purpose.

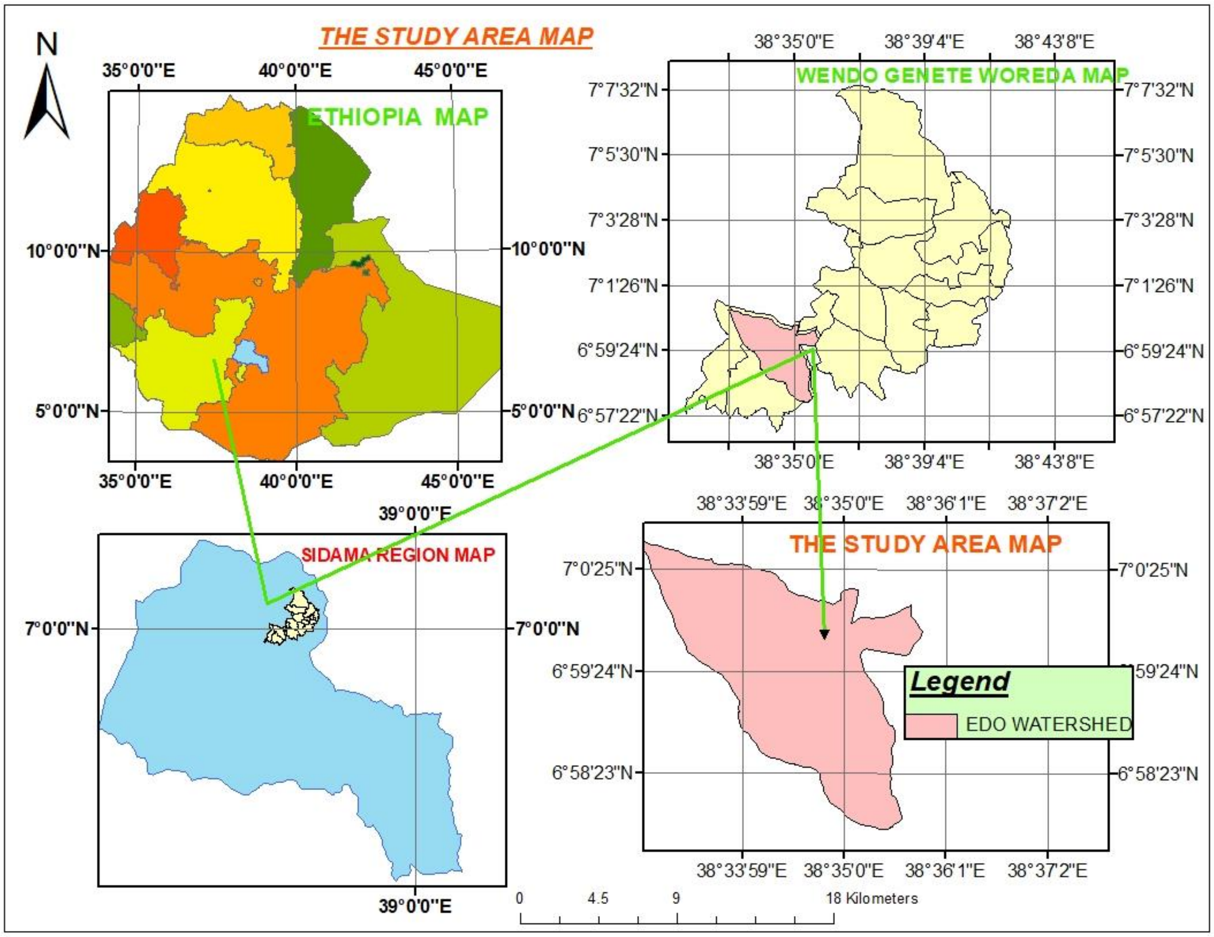


Figure 3. 1 location map of the study area

3.1.1. Climate

The climate in the study area is sub-tropical (local classification of Woina Dega) and is characterized by large seasonal fluctuations in air temperatures and rainfall (Belay, 2016). It has a tropical wet-dry high climate, which is characterized by marked seasonal contrast, unreliable precipitation, and a dry winter season of two to four months. It has a bimodal rainfall distribution with two rainy seasons, May to June, and more extensive in July to September. There is also a characteristic of the long dry season from October to February. The total annual rainfall range is between 800 mm to 1600 mm. On the other hand, the average annual temperature varies between 18°C and 21°C. In most parts of the Wondo Genet area, the Woina Dega (sub-tropical) agro-climatic type prevails (Figure 3.2).

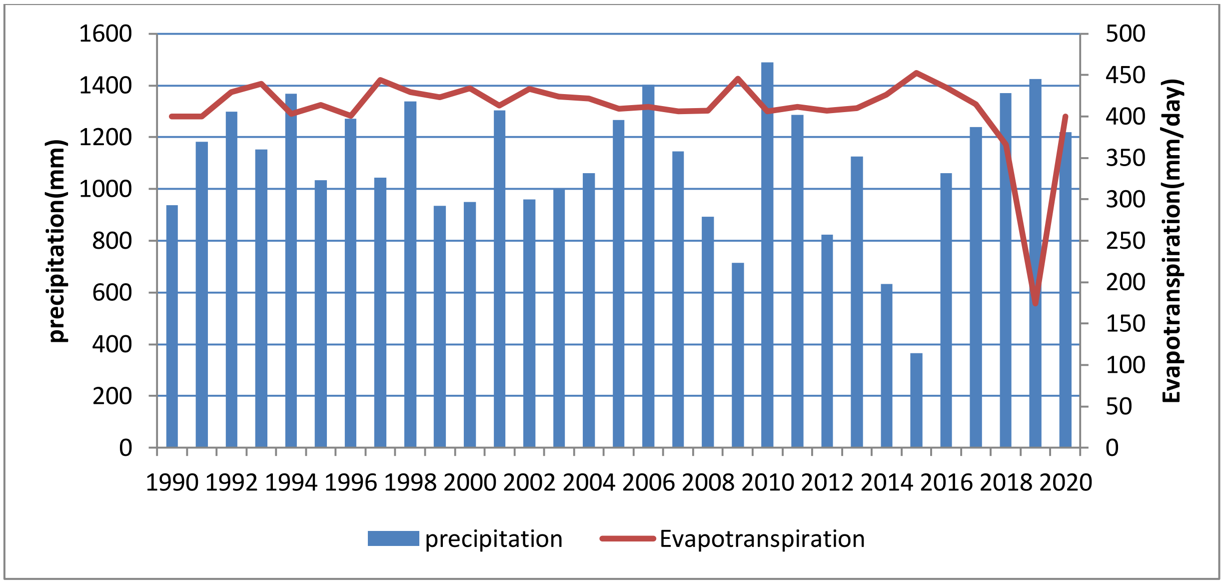


Figure 3. 2 Annual precipitation and potential evapotranspiration (PET)

3.1.2. Land use land cover

Land-use changes hold major repercussions on sustainable development and the livelihood of living systems as they contribute to changes in the biogeochemical cycles of the earth. Such changes also affect the atmospheric levels of greenhouse gases which are major causes of global climatic changes (Turner et al., 1995). Indeed, land-use and land-cover changes are significant to a range of themes and issues that are central to the study of global environmental changes. The terms land use and land covers are not synonymous.

Land cover commonly refers to the type of vegetation that covered the land surface but has now broadened subsequently to include human structures, such as buildings or pavement, and other aspects of the physical environment, such as soils, biodiversity, and surfaces and groundwater (Moser 1996, cited by Briassoulis, 2019). Land use involves both how the biophysical attributes of the land are manipulated and the intent underlying that manipulation (Turner et al. 1995).

The land cover of an area is governed by its geographic, climatic, and ecological conditions. At the Edo watershed, crop-livestock mixed subsistence farming is the primary source of livelihood and rain-fed agriculture predominates. Some farmer produces vegetable during the dry period using a hand-dug well as an irrigation water source.

The majority of the land use types are agricultural, chat, grassing land, and Enset. The agricultural land use covers more than average width and largely hill (flat) slopping regions. The most significant crops that grow in the area of the Edo watershed are Enset, chat, maize, and coffee. Due to the low rainfall amount and high rate of evaporation and transpiration during the Belg season, there was no crop grown during this period i.e. farmers were producing once a year. Recently, with the use of groundwater, farmers are producing twice a year. In addition to the above cereals, cultivation of the most commercial crops in the watershed such as chat is possible during the dry season. Almost half of the watershed is covered by intensively cultivated land.

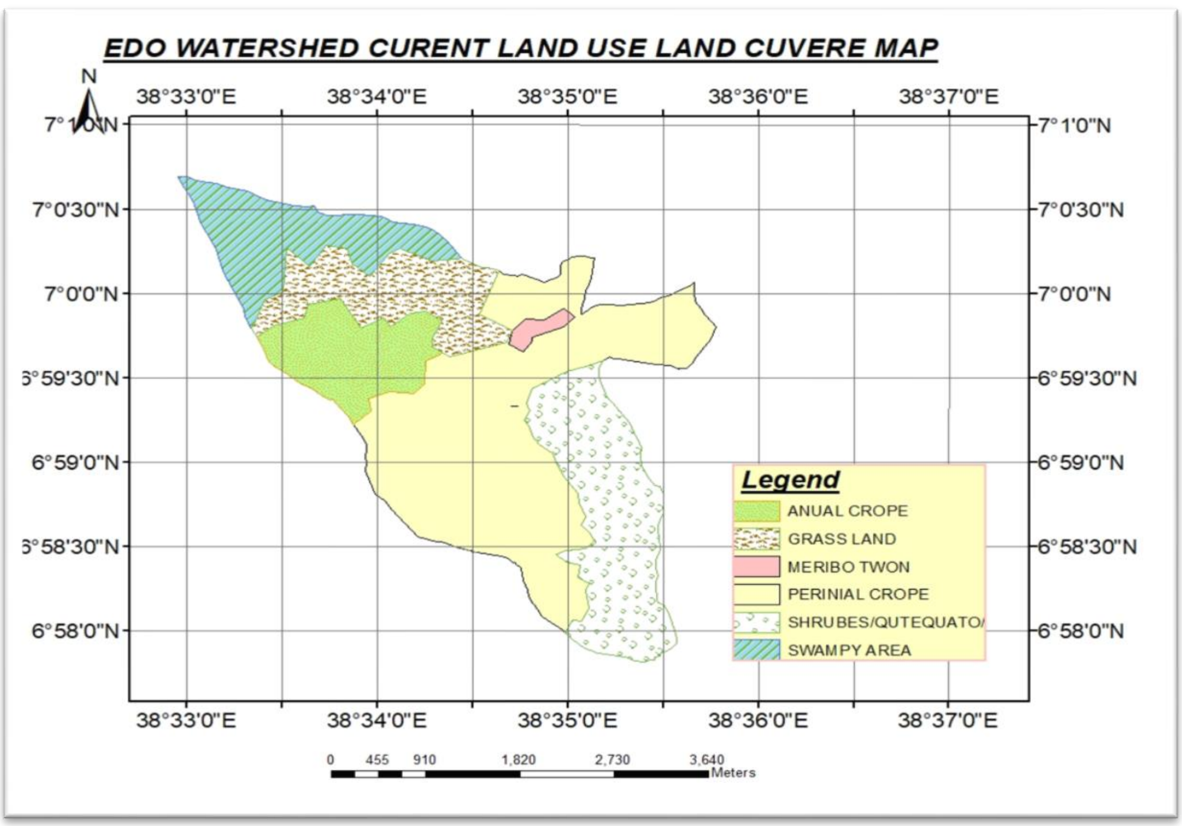


Figure 3. 3 Land use land cover map of Edo watershed

Table 3. 1 Percentage of each land use land cover in the study area

No	Land use land cover classes	Area(ha)	Percentage
1	Perennial crop	717.5	53.76
2	Annual crop	29.49	2.21
3	Grassland	249.5	18.7
6	Shrubs/qutikoato	237.28	17.76
7	Meribo Twon	11.82	0.9
8	Swampy area	89.26	6.68

3.1.3. Soil type and distribution

Based on color, the local people identify four soil types: red color (Forefor), black color (Mezega), grey-brown (Bunama), and dark brown (Abolse) as dominating the areas (Bewket and Belay, 2013). Wondo Genet comprises escarpments, ridges, plateaus, undulating to rolling and dissected plains, depressions, and swamps. Most of the bottomlands are flat, but some of the areas at the border have deep gullies and degraded lands caused by erosion and deforestation. Besides, the upper part of the area is dominated by a huge mountain known as Abaro. Due to the variation in landforms, the soil types also show a variation. Though there is variation in color and texture of soil from area to area, the dominant soil, which covers a large area of the Woreda, is sandy loam.

Clay loam with reddish color is also found in some parts of the area. Dark brown with loamy to loamy sand texture soil is also visually observed in some parts of the area. The soils are developed on recent volcanic deposits of ignimbrite, ash, lava, and tuff, which form the gently undulating plain characteristics of the area. Generally, the soils are fertile except for soils in sloppy lands whose fertility is reduced due to low organic matter. Soil exhaustion due to long-continued plowing, soil erosion losses due to deforestation, overgrazing, and extensive farming are some of the causes of loss of fertility in the area (CO-SAERSAT, 1999). Dark reddish-gray, very dark gray, and gray sandy loam predominantly occurred on hilly and gently slope parts of the study area. The watershed has Eutric fluvisols, Chromic Luvisols, and Swamps in general, and is most intensively cultivated refer to Table (3.2) and Figure (3.4).

Table 3. 2 Soil group and its percentage area

Major soil type	Area (ha)	Area (%)
Eutric fluvisols	1774.6	83
Chromic Luvisols	217.99	10.31
Swamps	946.2	6.68

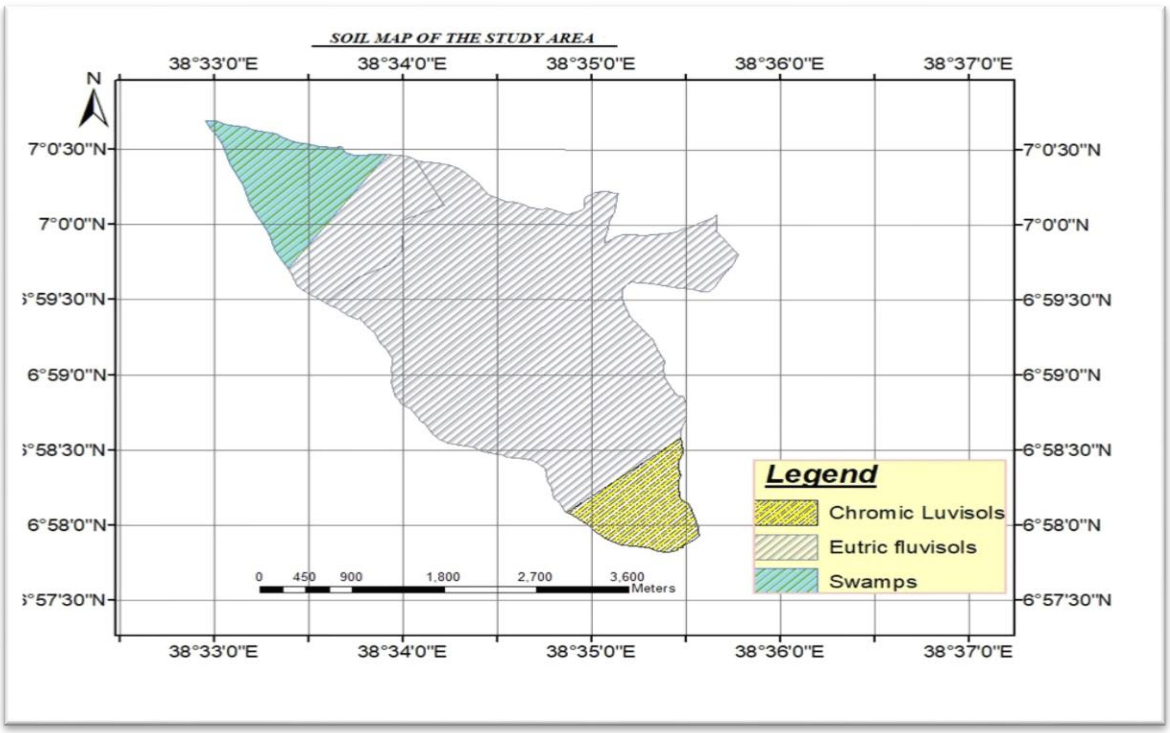


Figure 3. 4 Soil Map of the study area

3.1.4. Geology

The main Ethiopian Rift Valley is divided based on structural features into three geographic areas; represented by the northern (Fentale Nazret), the Central (Nazret Awassa), and the southern (Awassa-Konso) sectors. The central sector, where the Awassa lake catchment belongs is an asymmetric rift basin where both sides of the rift margins are fully defined except in the region between guraghe and Sodo of the western escarpment and the Shashemene area of the eastern margin (Tadesse and Zenaw, 2003).

Concerning geology, the Wendogenet area is created by Corbett rhyolitic ignimbrites whose surface is deeply lateralized. When soil cover is thin or absent, the lithologic and tectonic characteristics of the bedrock play dominant roles in aquifer recharge. Fractured bedrock surface and steep or vertical bedding greatly increase infiltration, while layers of unfractured bedrock sloping at the same angle as the land surface may almost eliminate it. Mature karst areas, where rock porosity is greatly increased by dissolution, generally have the highest infiltration capacity of all geologic media (Alley, 2009).

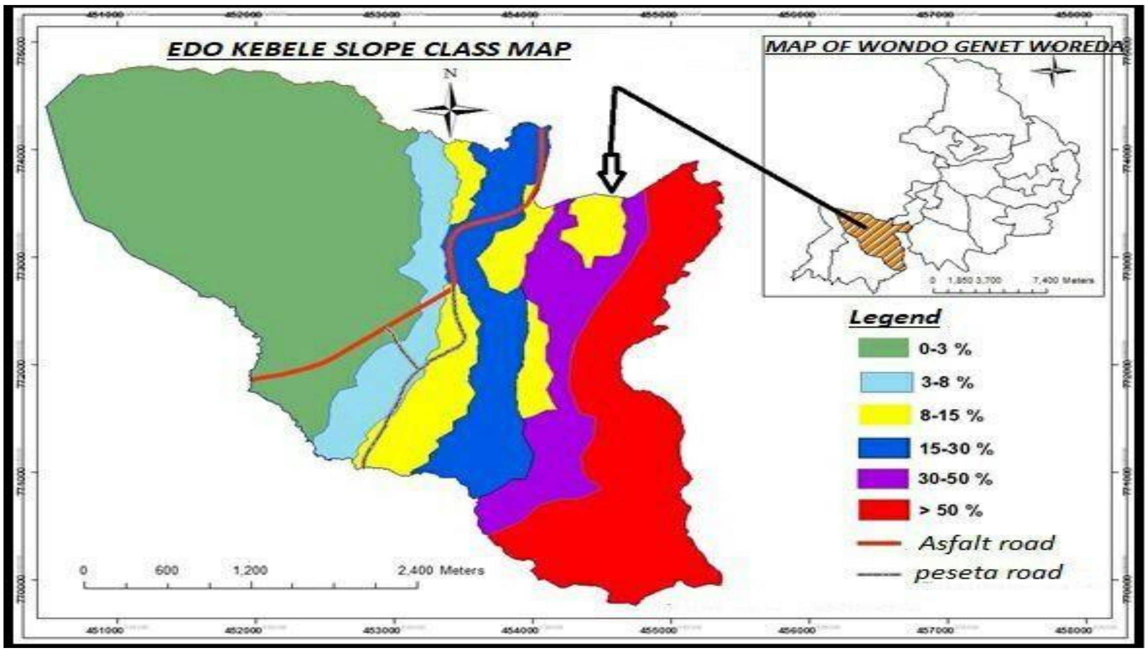
According to Tefera et al. (1996), cited in Walker et al, (2016), Bedrock geology consists of Cenozoic basalt and trachyte that are variously massive, fractured, and vesicular. Above the bedrock, it lies with weathered basalt regolith, overlaid by red clayey loam soils (nitisol). The superficial materials of the floodplains are occasionally very sandy and gravelly though deep and wide desiccation cracks suggest high-clay content (Vertisol).

3.1.5. Geomorphology

The altitude of the Edo watershed is found between 1701 and 2000 meters above sea level. The slope map was taken from the Wondogent agricultural office so the watershed is grouped under Woyina Dega and Dega local agro-ecological zone. The flat low land of the study area has an average elevation of about 2609m above sea level. The area comprises the hills of Abaro, Bachil Gigissa, Gariramo, Kentere, and Cheko, and the depression is surrounded by these hills. The height of land varies between 2,580 m a.s.l. at Abaro and 1,600 m a.s.l. around the marshy area. The higher altitudes and steep slopes support natural forest and lower altitudes and the gentle terrain consists mainly of farmlands.

The forests found in Wondo Genet occupy most of the Northeastern parts of the area. The hillsides and their foot belong to most of these forests. Based on the FAO classification of slope percent, states that areas with 0-3% of the slope are excellent from the point of view of groundwater occurrence, while the areas with greater than 30% slope have poor groundwater prospects. Areas with a low slope have a greater opportunity for recharge than areas with a high slope. The majority of the study area has a flat slope. However, the slight variations in the slope of the study area (0 to 42.734%) by classifying the entire area into six slope classes i.e., 0-3, 3-8, 8-15,15-30,30-50, and >50 %.

The areas with a slope of 0-3% were assigned with the highest rating values, whereas the areas that have a slope ranging between 3-8% were considered moderate from the groundwater recharge perspective. The areas that have a slope between 8-15 % and those with a slope that is more than 15% were considered as low and very low respectively for the suitability for groundwater recharge. (Figure, 3.5) illustrated the generated slope suitability map of the study area.



source: Wondogenet agricultural office

Figure 3. 5 slope map of Edo-watershed

3.1.6. Socio-Economy

To the (WANRO,2019) the total population of Wondo Genet woreda is estimated at,132,275 people in an area of about (225Km^2). One of Wondo Genet watershed is Edo which has a population of 12248. The livelihood of the community in the catchment is mainly based on mixed farming (crop production and livestock rearing) and agriculture is the main source of income for the population and is characterized by cash crop (chat) production and "Enset" as a major livelihood strategy. Trade and services activities are going on at the center of the Woreda. "Enset" is mainly used for household consumption purposes the major livestock managed in the area include cattle, cows, horses, donkeys, sheep, chickens, and goats

(WWAO, 2019). The water abstraction survey was done in Edo kebele under the hand-dug well user's farmers. In the Edo watershed, 59 farmers were used for the abstraction survey and 15 of them were none of hand-dug well. The survey includes water source for irrigation, domestic and livestock, type of irrigation technology used, type of vegetables planted, crop cultivated, amount of water abstracted, etc. The respondent owns the main sources of water for small-scale irrigation purposes and the communities own some of the sources.

3.2. Materials

The following materials were used for different activities to accomplish this study.

Table 3. 3 List of materials used in this study and their purpose.

No	Material	Source	Purpose
1	GPS	-	Study area delineation, and Ground truth data collection
2	Arc map 10.3	From USGS website	For image classification
3	Mendeley Desktop	HTTP:/Mendeley/free download	To organize journals and other material for citation
4	Microsoft Excel	Microsoft-office	For data analysis
5	Hydrus-1D	WWW.Pc-Progress.Com	For estimation of recharge

3.3. Data Collection

3.3.1. Hydro-meteorological data

The base stone of any good groundwater analysis, including those analyses whose objective is to evaluate the groundwater potential and searching alternative management strategies, such as the availability and accessibility of high-quality data (Alley et al., 1999). Therefore, to satisfy the objectives of this research different quantitative analyses are supported by various quantitative and qualitative data collected from both primary and secondary data sources as required by groundwater recharge evaluation.

3.3.2. Climatological data

Climate data comprises the average of atmospheric pressure, temperature, relative humidity, wind speed, and rainfall and consists of many other meteorological elements over a long portion of time in a specified area. The factors which have a great effect on characteristics of climate become numerous; and also the significant factors are; latitude, altitude, the density, and type of vegetation cover. The Climatic elements have an on each other in complex conditions by which an easily done series of actions are triggered to begin others to take place.

All of these climate elements and their great interaction with physical aspects cause to occur in the hydrological series of actions such as rainfall, runoff, recharge, and dynamics of shallow groundwater. To analyze various hydrologic cycle components, long-term meteorological data were obtained from the National Meteorological Agency of Ethiopia (NMAE) at 5 separate stations most suitable for data availability and position concerning the study area. These stations were most suitable based on the length of data length of time, particular position, and relative measured standard of their facts and statistics used for analysis. In some of the stations near to study area in the Edo watershed, the climate records were not run to the full extent, as a result, some desired results were carried out using the linear correlation between the nearest stations.

3.3.3. Rainfall data

The daily precipitation data for thirty-one years from five gauging stations (1990- 2020) within the catchment were collected from the metrological agency of Ethiopia. The longitude, latitudes, and elevations of the seven selected rainfall stations are given in below.

Table 3. 4 Location of selected rainfall stations within the catchment

Station name	Mean annual rain fall(mm)	The area represented by the station(Km^2)	Elevation m.a.m.s.l
Wondogenet	1102.792	300.93	1770
Hawassa	992.3367	519.87	1701
Shashemene	940.8851	139.53	1943
Haisawita	1112.321	221.78	2249

Yirba	1088.522	273.2	2034

3.3.4. Groundwater data

Groundwater levels were monitored in 25 hand-dug wells spread in locations within the Edo watershed. Selected farmers are responsible for recording water levels in the well once per week starting from 2013 up to 2014. For further detail, the locations and coordinates of the wells are shown in annex 1.8. The change in water level was calculated as the difference between the level measured today and the level measured the next time from the ground surface. For detailed well location and depth see annex 1.8.

Figure 3. 6 Typical household hand dug well

3.3.5. Soil water data

Soil water content measurements were conducted at the two defined/selected conserved land and bare land. At each selected site both conserved and bare land SWC was measured at different points respectively from each selected site. For calibration of the soil water content was determined using the gravimetric method by taking a soil sample from each selected site. In this study, the off-site was used to measure the soil water content up to a soil depth of 40 cm, and 100cm in the soil profile.

3.3.6. Soil properties sampling

For this study, a 1m × 1m × 1m pit was excavated from one of the representative places to determine the physical properties of the soil in the study area. Therefore the soil's physical properties such as texture, particle density, bulk density, field capacity (FC), and permanent wilting point (PWP) were determined by taking soil samples at each horizon of the soil to estimate Hydrus-1D model parameters. Soil samples were analyzed at S/N/N/P Design Supervision works Enterprise and Hawassa university soil laboratory. Soil texture was determined in the laboratory using the hydrometer method. Field capacity and permanent wilting point were determined at the suction of 33 kpa and 1500 k using pressure plate extraction (Botula et al., 2012). Bulk density was determined from undisturbed soil samples taken at each horizon using a core sampler.

Figure 3. 7 Soil sample taken for physical properties analysis

3.4. Method of Analysis

In order to effectively implement the study, the structural setup of the approach (input/output relationships) is shown in Figure 3.8. Figure 3.8 shows the schematic representations of the steps to be conducted in this research. It is designed to show how the parameters are interlinked each other with the flow of the system for estimating groundwater recharge. The data collected from each selected site were arranged and the quality was tested before starting to carry out any analysis. Then the collected data were analyzed by using the Hydrus-1D model. During the analysis soil water content, groundwater recharge, unsaturated hydraulic conductivity, and actual evapotranspiration were the expected output from the model simulation. Then the results of the model were evaluated by both graphical and statistical methods. In the graphical approach, the measured and simulated soil water contents were plotted as a function of the soil depth at different times. The statistical approach involved the calculation of the root mean square error (RMSE), Coefficient of determination (R^2), and mean bias error (MEB).

General Framework

The general framework used for this study is illustrated by the following flowchart

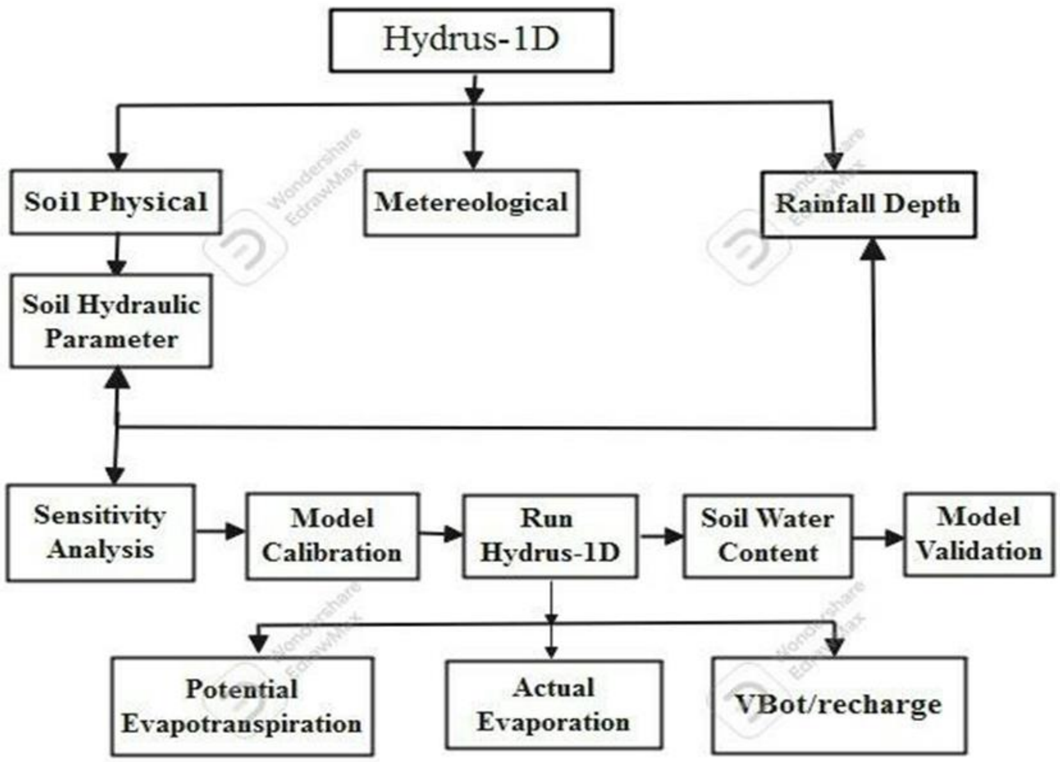


Figure 3. 8 Hydrus model Input-output flow chart

3.4.1. Hydrus-1D Model description

The one-dimensional Hydrus-1D computer program (Šimůnek et al., 2013) which based on Richards equation was selected to simulate soil water dynamics and estimate the groundwater recharge by using metrological data in the study field. Since the water flow in the soil profile between the soil surface and groundwater table (unsaturated zone) is predominantly in the vertical direction, there was no need to use a model such as Hydrus (2D or 3D) that would consider multiple dimensions (Li et al., 2015, van Dam et al., 2004). Therefore Hydrus-1D model can be used to estimate groundwater recharge.

HYDRUS-1D solves the “mixed form” equation (equation 4-1) by using Galerkin-type linear finite element schemes (Simunek et al., 2013).

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial z}\left[K(h)\left(\frac{\partial h}{\partial z} + \cos\alpha\right)\right] - S(h,t) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

Where h = hydraulic head (L); K (h) = hydraulic conductivity of soil (L/T), z = soil depth (L); S (h, t) = sink (root water uptake rate) in space and time, and h_0 and h_t are the initial and boundary condition potentials, respectively. Where h is the water pressure head (cm), which is a measure of the degree of suction pressure in the unsaturated zone, a variable that becomes zero when the soil pores are filled with water. θ is the volumetric water content (cm^3/cm^3), t is time (day), z is the spatial coordinate positive upward (cm), and S is the sink term (cm^3/cm^3), and it represents water uptake, usually from the root zone of a soil column via transpiration, α is the angle between the flow direction and the vertical axis (i.e.,$\alpha=0^0$ for vertical flow, 90^0 for horizontal flow, and inclined flow. K, the unsaturated hydraulic conductivity function, is a function of the pressure head, and the saturated hydraulic conductivity, K_s (cm/day).

To solve Equation (1), information is needed on the water retention (θ (h)) and hydraulic conductivity (K (h)) functions relationships (Stolte et al., 1996). The soil water retention, θ (h), and hydraulic conductivity, k (h) functions according to (Van Genuchten, 1980), are given as

$$\theta(h) = \frac{\theta_s - \theta_r}{[1 + |\alpha h|^n]^m} + \theta_r (h < 0), \theta = \theta_s (h \geq 0) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..2$$

θ (h) = θ_s, h ≥ 0

$$k(h) = k_s s_e^1 \left[1 - \left(1 - s_e^{1/m}\right)^m\right]^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..3$$

Where θ(h) is the water content at matric potential, θ_r is the residual water content (cm^3/cm^3); θ_s is the saturated water content which is taken as the measured total porosity (the water content at a matric potential of 0) (cm^3/cm^3); α, m and n are empirical shape factors in the water retention function which describes the shape of the function, where m=1-

1/n; K_h is the hydraulic conductivity at matric potential; K_s is the saturated hydraulic conductivity (cm/day); l is a parameter describing the pore structure of the material in the hydraulic conductivity function and S_e is the effective water content, which is defined as

$$s_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} \quad \ldots\ldots 4$$

The sink term (S) in Equation (1) is defined as the volume of water derived from a unit volume of soil per unit time by plant roots. It accounts for actual root water uptake equivalent to actual transpiration, calculated by the model using the Feddes equation (Soylu et al., 2011).

3.4.1.1. Hydrus- 1d input parameters

Some of the parameters required by the model could be measured directly in the field such as soil physical parameters. Boundary conditions for the topsoil surface and bottom layers of the soil profile have to be set to start simulations in Hydrus-1D. The soil profiles were described at the field and the physical properties (soil texture, field capacity, permanent wilting point, bulk density, and particle density) were determined at each soil horizon which is used to determine input parameters of the Hydrus-1D model. Rainfall and meteorological data including Daily maximum and minimum temperature, relative humidity, wind speed, and sunshine hours were also used as an input to Hydrus- 1D model to estimate evapotranspiration using the Penman-Monteith method.

3.4.1.2. Estimation of soil hydraulic parameters

Actual measurements of soil hydraulic properties are often prohibitively costly and time-consuming to obtain. As a result, several indirect methods ranging from simple lookup tables to methods with more physical foundations have been developed (Valiantzas and Londra, 2008). Receptivity and conductivity functions can be formulated indirectly from empirical non-linear regression equations and/or methods with more physical foundations (Van Genuchten, 1980; Mualem, 1976). The Van Genuchten – Mualem (VGM) model consists of five parameters: residual soil water content (θ_r), saturated soil water content (θ_s), shape parameters (α and n), and saturated hydraulic conductivity (K_s). These parameters can be determined by making use of a computer program called ROSETTA (Schaap et al., 2001).

The ROSETTA program consists of five hierarchical pedotransfer functions (PTFs) with varying degrees of input data requirement. The PTF(pedo transfer functions) (Wang et al., 2009) is used here to determine the above five parameters from measured sand, silt, and clay percentages (Table 4.1) show the main VGM parameters estimated in our study area where the Edo watershed are located (Figure 3.1). The reliability of ROSETTA has been assessed in various studies (Scott et al., 2000; Abbasi et al., 2004) which compared soil parameters derived from pedotransfer functions with those determined from model calibration.

3.4.1.3. Initial and boundary condition of Hydrus model

There are two options in Hydrus-1D for supplying initial conditions: pressure head or moisture content. In this study, the pressure head is used as the initial condition for all soil materials in the flow system as it is known to exhibit lesser spatial variability than that of moisture content. The upper boundary condition in the model was defined by an atmospheric boundary condition with surface runoff using potential evapotranspiration (ET0). For this study, ET0 was calculated by using the Food and Agricultural Organization (FAO) Penman-Monteith equation (Allen et al., 1998) using recorded meteorological data.

According to the reference Allen et al., (1998), the FAO Penman-Monteith method is physically based and can be used to predict ET_P in a wide range of locations and climates, even in data-scarce situations. The groundwater table in the study area was deep enough to exclude their influence on water movement in the rooting zone of the plant. Due to this reason, the free drainage (Rainfall infiltrates beneath the plant root zone) was specified to describe lower boundary conditions of the soil profile.

The sink term represents the volume of water removed per unit time from a unit volume of soil due to plant water uptake (Botros et al., 2012). The estimation of sink term is particularly important in shallow water level aquifers where water may initially contribute to groundwater storage but might later be extracted by transpiration. To better estimate, this flux, a fine discretization of the soil profile is implemented specifically in the root zone and lower boundaries where highly variable fluxes are expected see Figure 3.9.

The sink term is calculated as a function of potential transpiration and the pressure head with a Feddes type uptake function (Feddes et al., 1978). Note that, Hydrus-1D, being a Richards's equation-based finite element code, allows water to move up or down depending on the pressure head gradient. Measured rainfall application depths were considered as time-variable boundary conditions. Seven soil layers (0-20 cm of layer 1,20-40 cm of layer 2, 40-48 cm layer 3,48-60 cm of layer 4,60-80 cm of layer 5, 80-89 cm of layer 6, and 89-100 cm of layer 7) were considered for simulation.

3.4.1.4. Space and Time Discretization

Temporal and spatial discretization is the basis of any numerical modeling. Spatial discretization of a soil column is done vertically along with soil profiles at all points of interest in the watershed. For example, Figure (3.9) shows a typical heterogeneous soil profile, about 1 meter long. The required soil hydraulic parameters for each zone are determined by making use of calibrated values in a computer program called ROSETTA (Table 4.1). The soil column is first discretized into equidistant point distributions (1 cm) by using the finite element module of Hydrus-1D (Simunek et al., 2005). The temporal discretization is designed in Hydrus-1D to automatically vary between preselected minimum and maximum time steps. The minimum and maximum time steps selected for this study are 10-5 and 372 days, respectively for each simulation year.

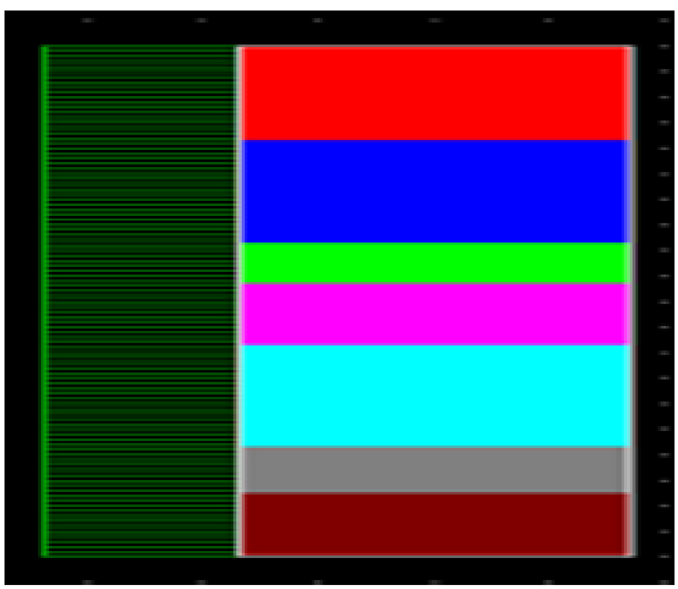


Figure 3. 9 Discretization of a soil column

3.4.1.1. Filling missing rainfall data

Most of the rainfall data in the study area may have short breaks in their records. Thus it is necessary to estimate the missing rainfall to keep the continuous-time series of the data. Several methods have for estimating missing rainfall data. There are station average method, normal ratio method, quadrant method, inverse-distance weighting method and regression methods. From five methods normal ratio is used for this study. In the normal ratio method, the rainfall P_A at station A is estimated as a function of the normal monthly or annual rainfall of the station under question and those of the neighboring stations for the period of missing data at the station under question. The general formula is given by

$$Pm = {}^{1}/N \sum_{n=1}^{n} \left(\frac{Nm}{Ni}\right) Pi$$

Whereas Pm = the computed missing data on each station

Nm = average annual rainfall at a rain gauge that the data were missed

Ni = the total average annual rainfall on the station

N = number of stations

3.4.1.2. Consistency checking

If the conditions relevant to the recording of rain gauge stations have undergone a significant change during the period of record, inconsistency would arise in the rainfall data of the stations. Checking for inconsistency was done using double mass curve techniques; the accumulated total of the individual gauge was compared with corresponding totals for a representative group within the station. If decided to change the regime of the curve that is observed needs further adjustment. In this case, a plot of the graph to check consistency from almost all straight lines the data is consistent with no need for further adjustment. Fig (3.10) expresses the consistency graph of the double mass curve.

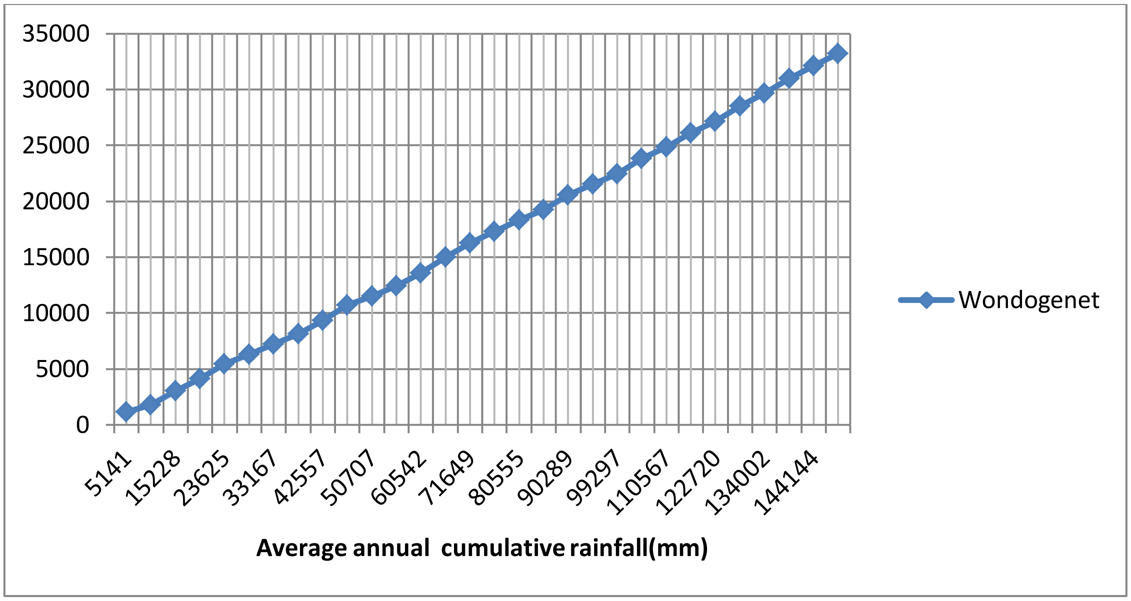


Figure 3. 10 Double mass carve to check the consistency

As it is depicted in the table below, the average maximum rainfall was recorded in August (151.8 mm) and the average minimum value was obtained in December (17.65mm). The majority of rainfall in the catchment is concentrated during the Ethiopian wet season (Kiremt) and the rainfall is uni-modal. The rainfall of the watershed is seasonal in which 70.96 percent of the total annual rainfall was covered from April to September. Climatic data from 1990 to 2020 is depicted in the table below.

Table 3. 5 long-term climate data near to Edo watershed

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rf (mm)	28.66	51.02	94.96	143.35	125.92	95.64	126.44	151.80	140.06	87.44	39.86	17.65
Tmax(°c)	29.0	30.2	30.1	28.7	27.5	25.9	24.7	25.0	25.8	27.1	28.2	28.3
Tmin(°c)	11.7	12.4	13.4	14.3	14.4	14.5	14.6	14.5	14.0	12.9	11.1	10.7
RH(%)	52.4	51.6	56.5	66.4	71.0	71.7	75.0	74.2	74.8	66.7	56.1	53.7

U2(m/s)	0.8	0.8	0.7	0.7	0.8	1.0	0.9	0.8	0.6	0.5	0.6	0.7
SSH(hr/d)	9.0	8.8	8.1	6.9	7.5	6.7	4.9	5.6	6.0	7.4	9.1	9.5

3.4.1.3. Sensitivity analysis

In a numerical (or otherwise) model, the Sensitivity Analysis (SA) is a method that measures how the impact of uncertainties of one or more input variables can lead to uncertainties in the output variables. The root zone modeling methodology adopted in Hydrus-1D is crucial for calculating recharge in arid and semi-arid regions. Several sources of uncertainty exist, however, in the vadose zone modeling approach used in this study. Possible sources of uncertainty include the values of several model parameters needed to run Hydrus-1D, including soil hydraulic parameters. However, to minimize the error, sensitivity analysis was done with several model parameters. For this study, Local sensitivity analysis (LSA) using the one-factor-at-a-time approach was used to understand the effect of each parameter on the model output since this approach allows clear identification of single parameter effects.

3.4.1.4. Hydrus model Calibration

Model calibration is generally defined as the process of tuning a model for a particular problem by manipulating the input parameters (e.g., soil hydraulic parameters) and initial or boundary conditions within reasonable ranges until the simulated model results closely match the observed variables. In the Hydrus-1D, inverse modeling is a form of model calibration. Inverse modeling requires a set of observed data, such as measured water contents or pressure heads. In model calibration, the objective is usually to obtain better model predictions. The Hydrus-1D models have an inverse modeling capability. In this study, field-measured data or observed water contents from the Edo watershed were used to calibrate the Hydrus-1D model during the simulation period 2021.

3.4.1.5. Hydrus model validation

One where observation of soil water content in soil profile up to 100cm for the model to show change of soil water content in each horizon. Simulated water content at this observation point was compared with field measured water contents (that were measured using GMcs) at 40 cm and 100 cm soil depth and for 100 cm it has 7 layers.

Table 3. 6 The soil physical properties of the study area for each soil horizon

No	Soil profile	%FC	%PW	Texture			
				%Sand	%Clay	%Silt	Class
1	Horizon B	27.71	9.63	50	6	44	Loam
2	Horizon A	34.89	23.06	32	10	58	Silt Loam
3	Horizon C1	28.24	19.99	70	6	24	Sandy Loam
4	Horizon E2	35.57	14.10	32	4	64	Silt Loam
5	Horizon E1	35.57	16.63	60	6	34	Sandy Loam
6	Horizon C2	36.98	18.91	54	0	46	Sandy Loam
7	Horizon D	23.41	13.70	56	0	44	Sandy Loam

FC-field capacity, PWP- permanent wilting point.

3.4.2. Model evaluation and statistical analysis

Pearson's correlation coefficient (r) and coefficient of determination (r^2) describe the degree of linearity between simulated and measured data (Moriasi et al., 2007). The correlation coefficient (r) and coefficient of determination (r^2), which ranges from 0 to 1, is an index of the degree of the linear relationship between observed and simulated data. If $r = 0$, no linear relationship exists. If $r = 1$ or -1, a perfect positive or negative linear relationship exists. Similarly, r^2 describes the proportion of the variance in measured data explained by the model. r^2 ranges from 0 to 1, with higher values indicating less error variance (Santhi et al., 2001; Van Liew et al., 2007). Although r and r^2 have been widely used for model evaluation, for several goodness-of-fit statistical indicators, mean bias error (MBE), root mean square error (RMSE), and correlation coefficient (r). These were defined as:

$$\text{MBE}=\sum_{i=1}^{n}\frac{(Si-Oi)}{n}$$

$$\text{RMSE}=\sqrt{\frac{\sum_{i=1}^{n}(Si-Oi)^2}{n}}$$

$$\text{R}=\frac{\sum_{i=1}^{n}(Oi-\bar{O})(Si-\bar{s})}{\sqrt{\sum_{i=1}^{n}(Oi-\bar{O})(Si-\bar{s})^2}}$$

Where Si is the simulated value, O_i is the observed value, $\bar{s}$ and $\bar{O}$ the mean of simulated and observed values respectively and n is the number of a data point. Values close to 1 and MEB and RMSE values close to zero indicate good model predictions. Values of R close to 1 indicate that the model explains well the variance of observations. R^2 describes the proportion of the variance in measured data explained by the model. It ranges from 0 to 1, with values greater than 0.5 considered acceptable. R^2 of 1 indicates a perfect fit between the simulated and observed data RMSE is an error-index statistic that measures the difference between simulated and observed values. The lower the RMSE and MBE value, the better the performance of the model (Moriasi et al., 2007).

Table 3. 7 Model performance Range

Rank	R^2	RMSE
Very good	0.75 to 1	0 to 0.5
Good	0.65 to 0.75	0.5 to 0.6
Satisfactory	0.50 to 0.65	0.6 to 0.7
Unsatisfactory	<0.5	>0.7

3.4.2.1. Evaluate actual evapotranspiration

Calculation of potential evapotranspiration was calculated in HYDRUS-1D using either the FAO recommended Penman-Monteith combination equation for evapotranspiration (ET_o) (FAO, 1990) or the Hargreaves equation (Jensen et al., 1997).

With the Penman-Monteith approach, ET_o is determined using a combination equation that combines the radiation and aerodynamic terms as follows (FAO, 1990):

$$ETo = ET_{rad} + ET_{aero} = \frac{1}{\lambda}\left(\frac{\Delta(R_n - G)}{\Delta + \gamma\left(1 + \frac{r_c}{r_a}\right)} + \frac{\rho c_p (e_a - e_d)/r_a}{\Delta + \gamma(1 + \frac{r_c}{r_a})}\right)$$

where ET_o is the evapotranspiration rate (mm/day), ET_{rade} is the radiation term (mm/day), ET_{aero} is the aerodynamic term (mm/day), λ is the latent heat of vaporization (MJ/kgMJ/kg), R_n is net radiation at the surface ($MJ/m^2/day$), G is the soil heat flux ($MJ/m^2/day$), ρ is the atmospheric density (kg/m^3), c_p is the specific heat of moist air (i.e., 1.013 kJ/kg/°C), $(e_{a-}e_d)$ is the vapor pressure deficit (kp_a), $e_a$is the saturation vapor pressure at temperature T (kp_a), e_d is the actual vapor pressure (kp_a), r_c is the crop canopy resistance (s/m), and r_a is the aerodynamic resistance (s/m). The potential evapotranspiration can also be evaluated using the much simpler Hargreaves formula (e.g., Jensen et al., 1997).

$$ET_p = 0.0023\ 17.8\ (T_m + 17.8\ )\sqrt{TR}$$

Where R_a is extraterrestrial radiation in the same units as ET_p (e.g., mm/d or$J/m^2/s$), T_m is the daily mean air temperature, computed as an average of the maximum and minimum air temperatures (°C) TR is the temperature range between the mean daily maximum and minimum air temperatures (°C).

3.4.3. Groundwater recharge estimation methods

3.4.3.1. Groundwater recharge estimation by using Hydrus-1D

The groundwater recharge from a watershed and daily bottom fluxes, as well as cumulative bottom fluxes, were assessed using the Hydrus-1D version 4.17 models (Simunek et al., 2013). Hydrus-1D solves the "mixed form" equation (equation 4-1, see section 3.4.1.) by using Galerkin-type linear finite element schemes (Simunek et al., 2005).

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left[K(h)\left(\frac{\partial h}{\partial z} + \cos\alpha\right)\right] - S(h,t) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

Where h = hydraulic head (L); K (h) = hydraulic conductivity of soil (L/T), z = soil depth (L); S (h, t) = sink (root water uptake rate) in space and time, and ho and h_t are the initial and boundary conditions, respectively. The sink term (root water uptake rate) was modeled using the following equation given by Feddes et al., (1978):

$S(h)=\lambda(z)\alpha(h)T_p$……………………………………………………………(2)

Where $\lambda(z)$ is the relative root distribution function, T_p is the potential transpiration rate, and $\alpha(h)$is a dimensionless water stress response function ($0 \leq \alpha \leq 1$) to account for reductions in uptake due to drought stress. For the simulation of water movement, the depth of soil profile was considered as 100 cm and seven soil layers at 0-20cm, 20-40cm, 40-48cm, 48-60cm, 60-80cm, 80-89cm, and 89-100 cm from the ground surface were taken for mass balance. The recharge rate was simulated on daily basis for each year independently during the period 1990 to 2020. The total simulation period was the period between the occurrence of the first and last rainfall events in that particular year.

The initial and final time steps were taken as 0.001 and 0.00001 respectively and the maximum time step was 372. Initial and boundary conditions were specified on a 100 cm deep vertical soil profile. The whole soil profile was discretized into 7 layers of 100 cm each. Initial conditions were selected as pressure heads in the soil profile on the day of the start of the simulation. In this study, the upper boundary condition was taken as the atmospheric boundary condition with surface runoff and the lower boundary condition was taken as the free drainage. The different water flow parameters namely, saturated water content (θ_s), residual water content (θ_r), inverse of the air entry value (α), pore size distribution index (n) saturated hydraulic conductivity (K_s) and pore connectivity parameter (l) for three different soil with 7 layers were estimated using bulk density and sand, silt, and clay percentage as input data. The particle size distribution and bulk density of soil are presented in Annex 1.4 and the water flow parameters are given in Table 4.1. The daily rainfalls were used as time variable input data.

3.4.3.2. Recharge calculation using the WTF method

The water-table fluctuation (WTF) method provides an estimate of groundwater recharge by analysis of water-level fluctuations in observation wells. The water table fluctuation method (WTF) is one of the most widely used techniques for estimating groundwater recharge over a wide variety of climatic conditions (Alexander, 2016). The use of the method requires knowledge of specific yields and changes in water levels over time. The WTF method is based on the assertion that rises in water levels in unconfined aquifers are due to recharge water arriving at the water table, and that all other components of the groundwater budget including lateral flow are zero during the recharge period (Islam et al., 2016).

The groundwater recharge rate can be estimated as the product of the water level rise and the specific yield of the groundwater aquifer material. The WTF method can be applied over longer time intervals (seasonal or annual) to estimate the change in subsurface storage (Islam et al., 2016). This method is based on groundwater levels are among the most widely applied methods for estimating groundwater recharge (Healy and Cook, 2002). The water-table fluctuation (WTF) has several advantages in estimating recharge rates including the simplicity and insensitivity to the mechanism by which water moves through the unsaturated zone (Healy & Cook, 2002).

The method is used at the scale of interest to basin hydrologic studies and the method requires no extensive in situ instrumentation network, its accuracy, ease of use, and low cost of the application in semiarid areas (Maréchal et al., 2006).

The WTF method was used in this study because frequent and accurate water level measurements were available in a well, and because the method is very useful for detecting temporal recharge variations (Healy and Cook, 2002). To assess the change in groundwater recharge during the rainy season, the water level was observed by monitoring wells spread within the study area. The following empirical formula was used for the estimation of change in groundwater storage (Orji et al., 2016).

$R = S_y * A * \Delta h / \Delta t$ ------------------------ (3)

Where S_y is the specific yield (storage) or the fillable porosity of the unconfined aquifer, A is the area influenced by the well and Δh is the difference in water level rise of the well at time difference Δt Specific yield is the volume of water released from a unit volume of saturated aquifer material drained by a falling water table (Sophocleous, 1991). The specific yield value for this watershed was used as 0.1 from (Patse, 2018). The sum of the percentage of saturated and hillside area contribute to the 52% of shallow aquifer present in the watershed of groundwater recharge storage (Setargie et al., 2021). In the Ethiopian rift valley, the area that contributes to the recharge is assumed approximately 35% (Ferede et al., 2020). The average value was used for this study saturated and hillside areas and rift valley basins. I.e. 45 percent of the watershed was assumed used for the storage.

3.4.4. Soil water content estimation method

SWC has an important impact on many fundamental hydrological processes. For this study, SWC can be measured using direct methods. The gravimetric method is the most direct method to measure SWC by taking soil samples from the field, then weighing, drying, and weighing in a soil analysis laboratory. The gravimetric sampling method gives accurate values of the SWC. The gravimetric method involves collecting a soil sample, weighing the sample before and after drying it, and calculating its original moisture content.

The gravimetric method is the oldest (other than the ancient method of feeling the soil) but continues to be the most widely used method for obtaining data on soil moisture. Because it is the only direct way of measuring soil moisture, it is required for calibrating the equipment used in the other methods. The collected sample was weighted immediately in the field off-site to control evaporation then put in an oven-dry for 24 hours, and then weighed again and measure the Weighted again after 24 hours to calculate the water content of the soil from both the conserved land and bare land for the estimation soil water dynamics.

3.4.5. Estimation of the intensity of conservation structures

The intensity of Conservation Structures is the most important factor to establish the relation of Groundwater Recharge with conservation structures (Patse, 2018). The intensity of Conservation Structures was calculated with the help of the given formula below as:

Intensity $=\frac{\text{NUMBER OF STRUCTURE}}{\text{AREA}}$ Where Area in Km^2, Intensity of Structures per Km^2……………………………………………(4)

4. RESULTS AND DISCUSSIONS

4.1. Model Parameterization

Hydrus-1D soil hydraulic parameters (i.e, θ_r θ_s , α, n, and K_s) derived from the observed soil physical properties by the ROSETTA computer program for soil water dynamics evaluation and assess the impact of land management practices on the groundwater, recharge was stated in Table 4.1.

Table 4. 1 Soil texture (%) and calibrated parameters at the Edo watershed

Units of VGM parameters : θ_r,s(cm^3/cm^3) Alpa (1/cm) k_s(cm/day)									
soil layer	Depth in(cm)	Sand (%)	Silt (%)	Clay (%)	θ_r,	θ_s,	α	n	k_s(cm/day)
1	0-20	32	58	10	0.048	0.418	0.004	1.675	40.45
2	20-40	50	44	6	0.034	0.402	0.012	1.487	42.64
3	40-48	70	24	6	0.035	0.389	0.038	1.445	58.47
4	48-60	54	46	0	0.024	0.431	0.018	1.462	92.5
5	60-80	56	44	0	0.023	0.428	0.021	1.446	89.52
6	80-89	60	34	6	0.033	0.394	0.025	1.416	51.19
7	89-100	32	64	4	0.037	0.447	0.005	1.695	83.4

θ_r- Residual soil water content, θ_s- saturated soil water content, α- Shape parameters, n-pore size distribution parameter, and K_s- Saturated hydraulic conductivity

4.1.1. Sensitivity analysis for Hydrus-1d model parameters

A simplified systematic sensitivity analysis was performed to know the influence of each parameter variations on the model output and then select the most sensitive parameters (Chang et al., 2007). The simulations result showed that the most important parameters for groundwater recharge were the soil hydraulic parameters. The Van Genuchten soil hydraulic parameters, θ_r, θ_s, and K_s have physical meanings, whereas the other three parameters are shape factors: α is inversely related to air entry pressure, n is a measure of pore

size distribution, and lumped parameter l accounts for pore tortuosity and connectivity. Strikingly, compared to the shape factors, the distribution of GR is not very sensitive to θ_r, and θ_s, even though the three parameters such as α, K_s, and n vary significantly in the measured data set.
The results indicate that θ_r and θ_s, are relatively unimportant for determining GR in the watershed. The shape of GR distribution is instead mostly controlled by the factor n when GR increases with increasing n values. In general, a coarser soil with larger pore sizes possesses a higher n value, which leads to a higher GR. As soil samples with larger n values have more weights for determining GR in conclusion, the spatial variability in n is extremely important for determining a GR and its spatial distribution in semiarid regions.

Compared with other parameters, Ks was the least sensitive it increases or decreases groundwater recharge by 16.3%. The lower or higher values of K_s, such as might be the case of a textural class of the soils, leading to lower or less runoff. From the result α, saturated hydraulic conductivity and pore size distribution parameter was the most important hydraulic parameters that affect Hydrus-1D model output. This result compared with others, Jimenez Martinez et al. (2009) reported that saturated hydraulic conductivity an increase or decrease groundwater recharge by ±15-20%, n and α was the most sensitive.

4.1.2. Hydrus-1d model calibration

Calibration of a model is used to investigate a good agreement among the parameters in the model in this particular study. The calibration process was implemented based on the Van Genuchten soil hydraulic parameter in the Hydrus-1D model. In this study, the residual water content (θ_r), the saturated water content θ_s, saturated hydraulic conductivity (K_s), whereas the other three parameters are shape factors: α is inversely related to air entry pressure, n is a measure of pore size distribution, and lumped parameter l accounts for pore tortuosity and connectivity.

The most useful list of main calibration parameters and corresponding measurement units of the Hydrys-1D model are given in Table 4.1. The soil physical parameters and moisture content of the soil were used for the calibration and validation process. The result shows that performance evaluating criteria in both observed and simulated soil moisture the static comparison has confirmed that the Hydrus-1D model is calibrated well in the modeling process. This calibration result was obtained with a Hydrus-1D model incorporated with the Rosetta soil hydraulic parameter, Table 4.2 shows the good agreement values created between calibrated and simulated soil moisture for the watershed.

The statistical model performance evaluation results for the calibration process are indicated in Table 4.2:- Mean bias error (MBE), correlation coefficient (r), and root mean square error (RMSE) were calculated as a model performance evaluation measure. Compared with others this result is consistent with that of (J. Šimůnek, 2012) R^2 0.998 MBE 0.00054, and RMSE 0.00 312. The difference is due to the ROSETTA and pedotransfer function process to calibrate. Accordingly, the calculated values of these model performance criteria have shown very close to their optimum best fit values. So far, the parameters and the model evaluation criteria of the observed and simulated soil moisture have shown that the model has well-calibrated. The model can then be used to simulate future soil water change and estimate the groundwater recharge in the watershed.

Table 4. 2 Calibrated soil hydraulic parameters

Depth(cm)	Parameters	R^2	RMSE	MBE
0-100	θ_r(cm^3/ cm^3)	1	0.006	0.00003
0-100	θ_s(cm^3/ cm^3)	1	0.00006	0.00002
0-100	K_s(cm/d)	1	0.028	0.0008

4.1.3. Model evaluation using field data

The soil water content was well simulated by the model for all input databases. The measured and simulated soil water content and input rainfall depth were functions according to given soil parameters in the Hydrus-1D model for the simulation period. For evaluating the accuracy of model output predicted soil water content from the observation node (at 0-20, 20-40, 40-48, 48-60, 60-80, 80-89, 89-100 cm soil depth) by Hydrus-1D compared with the observed SWC for all in each horizon. Hydrus-1D validation was done by using field data and model simulation value from soil moisture measured from each soil depth. In addition, the model is validated by a graphical technique that provides a visual comparison of measured and simulated soil water content. The recorded soil moisture data are important in evaluating the performance of Hydrus-1D. An atmospheric boundary condition with surface runoff and free drainage conditions are imposed at the soil surface and bottom boundary of the flow domain, respectively. Figure 4.1 compares the distribution of the simulated and measured water content at seven depths in the soil profile at the Edo watershed. Soil moisture correlations are generally found to be good in the all soil layer (0.997) root mean square error (0.13), and mean bias error (0.049603) see Table (4.3).

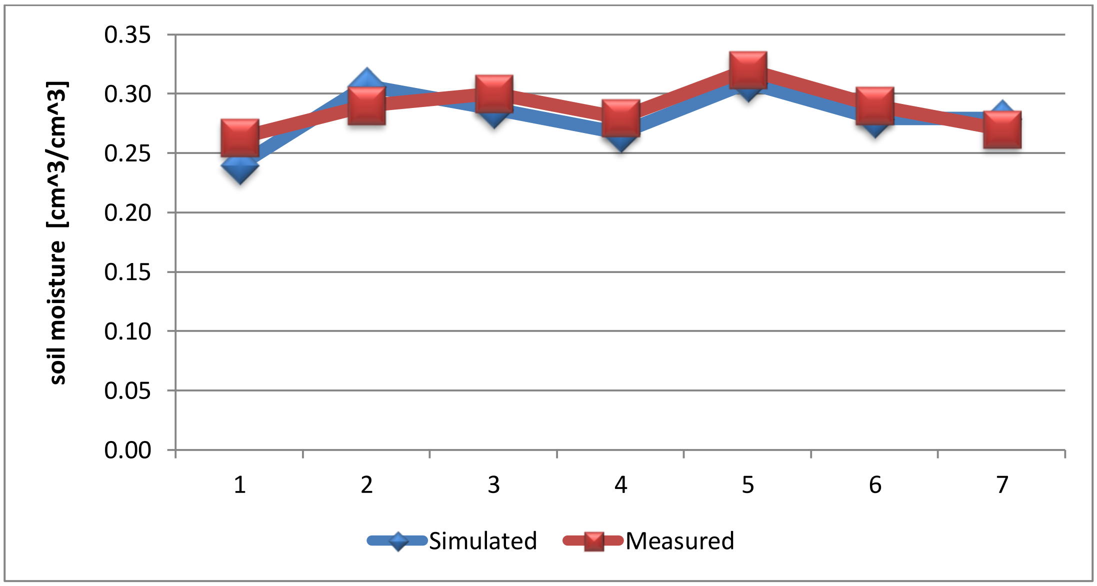


Figure 4. 1 Simulated versus observed soil moisture at each soil depth, Edo watershed.

Table 4. 3 Model validation values

Depth(cm)	R^2	RMSE	MBE
0-100	0.997	0.13	0.049

4.2. Groundwater Recharge Estimation

4.2.1. Recharge estimation by using Hydrus-1D

The average long-term annual groundwater recharge in the Edo watershed was simulated by the Hydrus-1D hydrological model. After evaluating the performance of Hydrus-1D using field data and calibrated VGM parameters, groundwater recharge is simulated by using the long-term climate data and calibrated VGM parameters. In a watershed total of 31 years of the recharge is simulated including the simulation period 1990-2020 see (Table 4.4). As a result, 297.889 mm of the average annual simulated groundwater recharge was simulated in the watershed. The average annual long-term groundwater recharge for the watershed was simulated as 26.92% of the average annual precipitation (1106.5) in the watershed. Based on that, the groundwater recharge in the Edo watershed was estimated (3, 976401.1 millionm^3), see (Figure 4.).

These results are consistent with those of others. (Sabrina Bruneau1, 2021), is reported that groundwater recharge is 38%-45% during the wet time of rainfall and the 29% of precipitation in the dry time or in the fall by using the Hydrus-1D model when compared with this result in watershed 26.9 % of precipitation is the GR the difference is due to the difference of time, rainfall, climatic condition, and the other issues which concerned is in study watershed the amount of rainfall soil textural parameters is one of the concerning points.

Zemedagegnehu,(2020) reported that the Hawassa catchment receives a mean annual rainfall of 1039.85 mm, and the mean annual surplus, which is available only for recharge is 20.3% of the mean annual rainfall by using the water balance method. When compared with this study the difference is 6.336% due to the conservation structure in the study site and rainfall. In addition to this evaporation is also one of the factors to make a difference why because the when the high temperature in the area there increases the evaporation rate due to the high latent heat energy due to sunshine hours. The other issue reported in the study is there is a lack of proper traditional fragmented or purely sectorial approach that is no longer viable and a cross-sectorial approach is essential in the basin for sustainable groundwater development and proper utilization and management.

Edo is one of the watersheds found around Hawassa catchment, and the difference made in groundwater recharge is as mentioned above the amount of rainfall and the flow parameters, and some conservation measure is taken to control runoff in the reclaimed land in the watershed by a governmental organization, NGO, and local farmers.

Figure 4.2 shows actual root water uptake and the actual surface flux due to infiltration of precipitation, and the actual root water uptake (transpiration) is significantly smaller during periods without precipitation or immediately after large rainfalls.

The estimated actual root water uptake rates are derived from the meteorological data. It shows Soil water heterogeneity and limited soil water availability were found to accelerate the root water uptake from the moist region to compensate for the reduced water availability in the dry zone.

Figure 4.3 shows the actual bottom flux, which represents deep drainage that occurs below the root zone. This flux will continue downwards by gravity until it eventually recharges the underlying aquifer. Note that most of the recharge corresponds to large rainfall events when the soil profile is saturated (and highly conductive).

Figure 4.4 shows the cumulative bottom fluxes; the actual surface flux (infiltration minus evaporation) is negative (downward) and represents infiltration, the actual bottom flux is negative (outflow) and represents recharge, and the actual root water uptake (transpiration) is positive (upward). In this study, only the first 100 cm of a deep unsaturated zone are considered for estimation of recharge due to the drainage condition of the watershed.

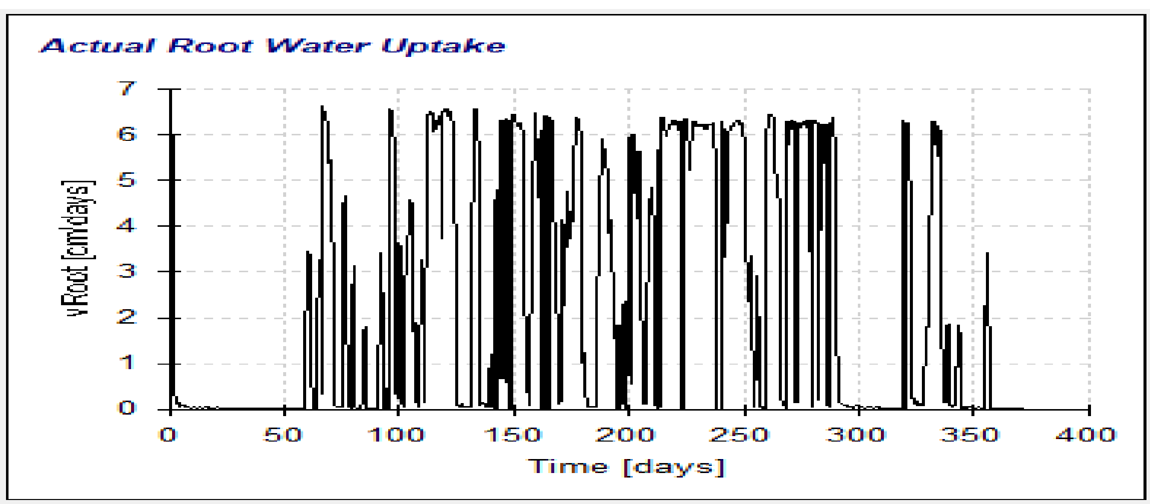


Figure 4. 2 Actual root water uptake versus time.

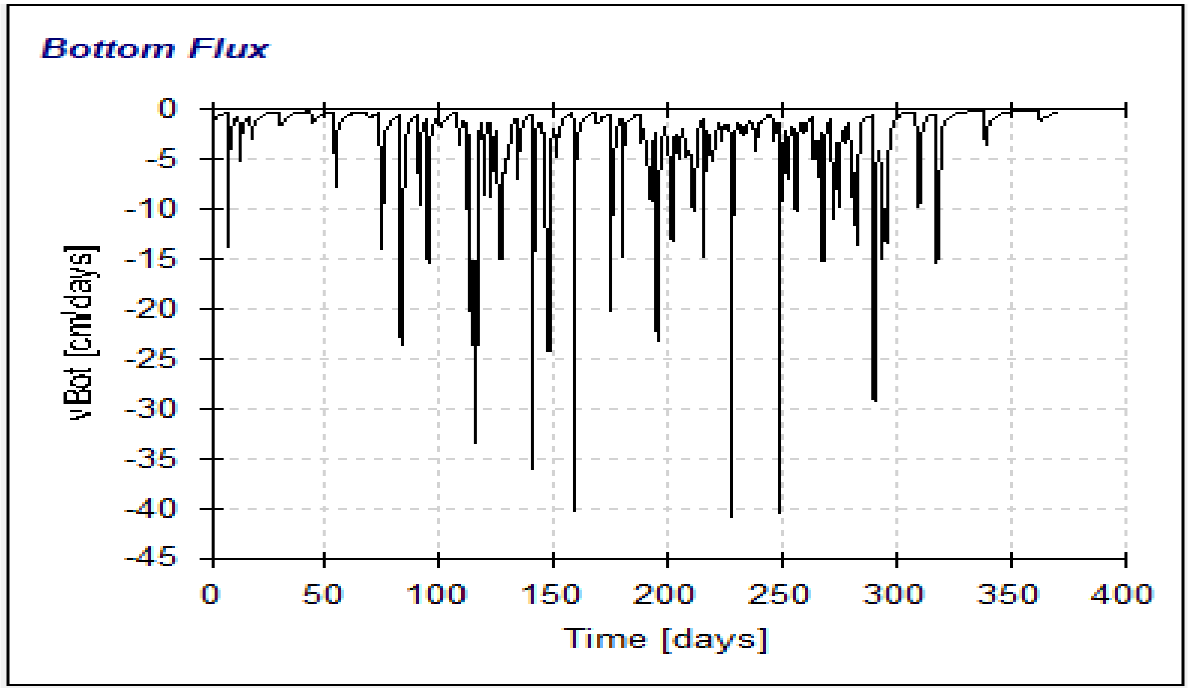


Figure 4. 3 Actual bottom flux (out of the soil profile) versus time.

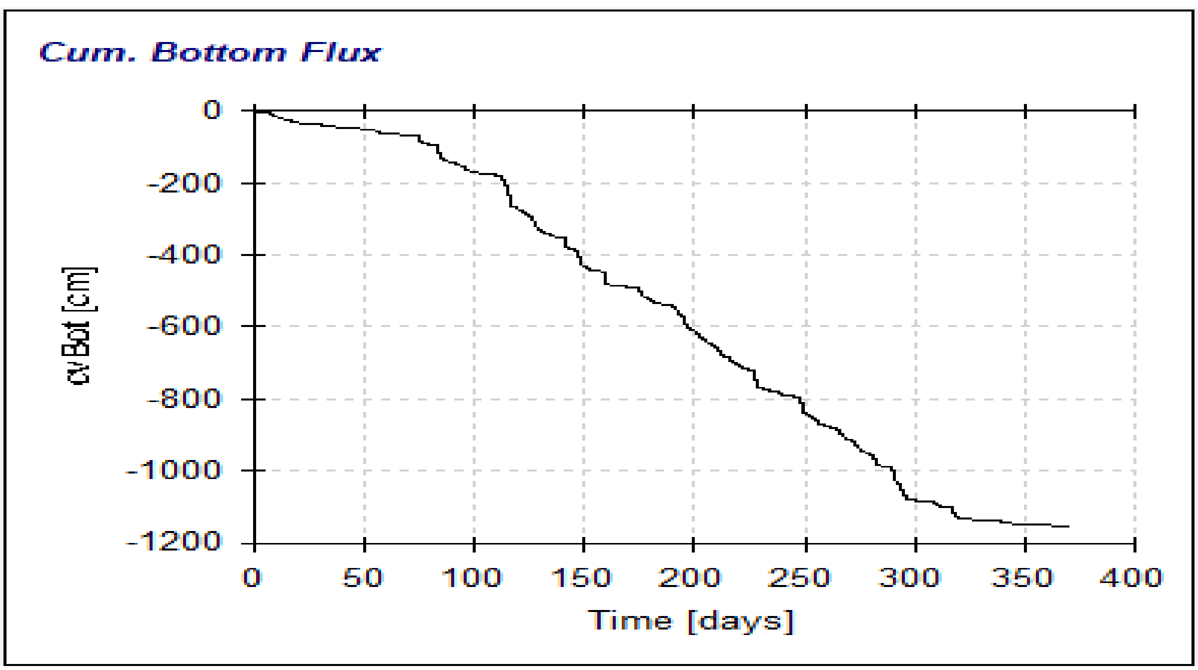


Figure 4. 4 Cumulative actual bottom fluxes (recharge) versus time

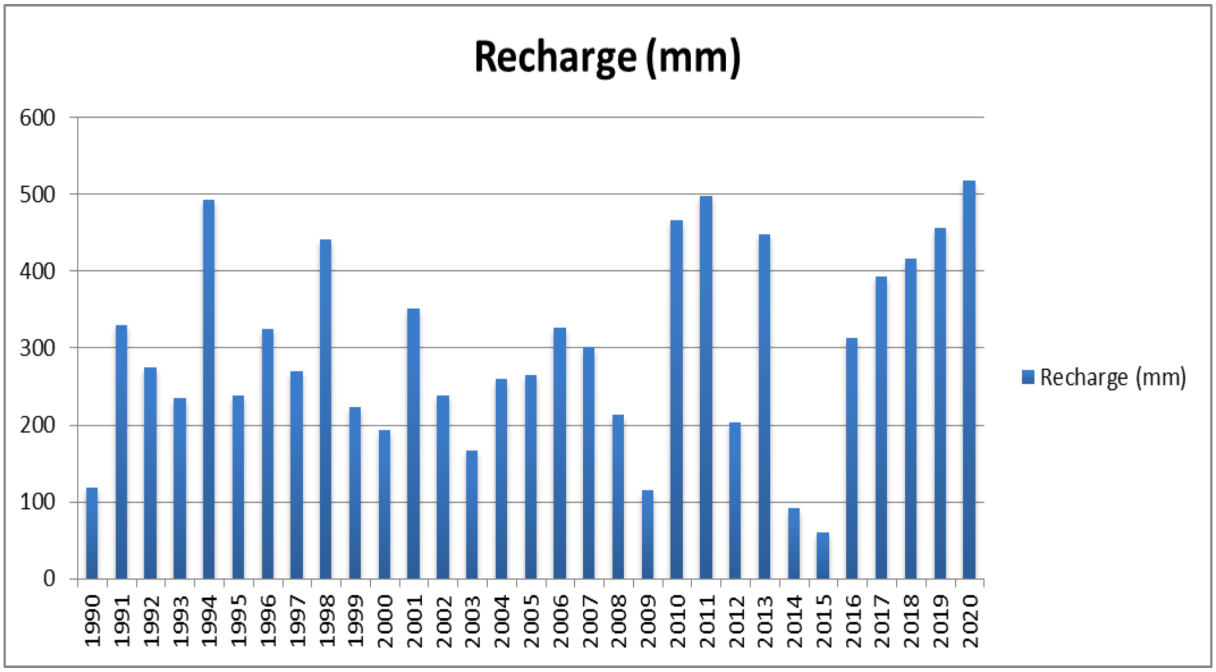


Figure 4. 5 Graphs show the annual groundwater recharge (mm) Hydrus-1D of the Edo watershed

Any information recharge estimation should give an indication of how recharge varies over time. Figure 4.6 shows the annual variation of recharge, along with precipitation and evapotranspiration, at the watershed.

Note in Figure 4.6 that recharge is decreased during the years when evapotranspiration is high and precipitation is low (e.g., 2014). Such dry years can also affect the magnitude of recharge the following year (e.g., 2015). This is because the precipitation received following a dry year has to satisfy the soil moisture requirement before it drains out of the soil column as recharge.

On the other hand, high recharge is estimated during the period when high precipitation and low evapotranspiration are observed (e.g., 2019). Such climatic condition generally results in high soil moisture condition. As a result, the precipitation that falls the following year can easily result in higher recharge values (e.g., 2020). Analysis of the result shows a wide variation, ranging from 1.33% to 18.5% of annual precipitation over the 31 years simulation period. This is a significant variation over the years, caused by antecedent soil moisture conditions and climatic conditions.

Table 4. 4 Annual Eto, Recharge, and precipitation

Year	ETO	Recharge (mm)	Precipitation(mm)
1990	400	117	939
1991	400	330	1182
1992	429	275	1300
1993	440	235	1154
1994	403	492	1367
1995	414	239	1035
1996	401	325	1270
1997	444	270	1044
1998	430	440	1338
1999	423	224	936
2000	434	194	949
2001	413	351	1305
2002	433	238	959
2003	424	167	1002
2004	422	260	1061
2005	409	264	1267
2006	412	327	1403
2007	406	302	1144
2008	407	213	892
2009	446	115	716
2010	406	465	1490
2011	411	497	1287
2012	407	203	824
2013	410	448	1126
2014	426	92	633
2015	453	60	366

2016	435	313	1062
2017	415	392	1240
2018	366	416	1370
2019	374	456	1425
2020	400	518	1218

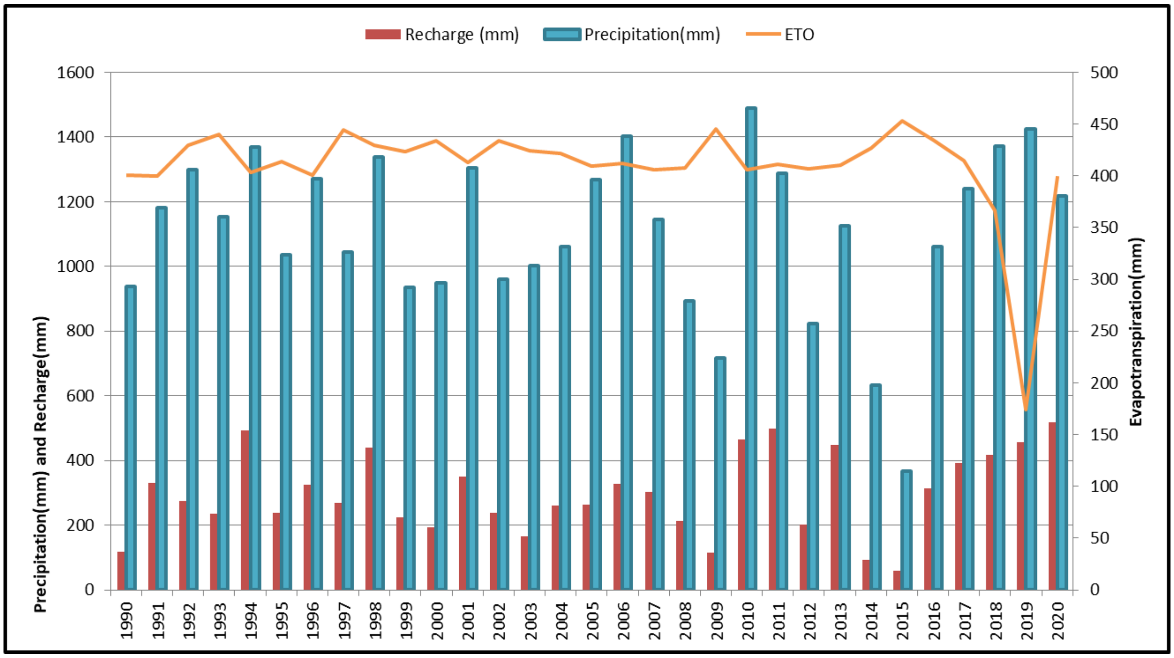
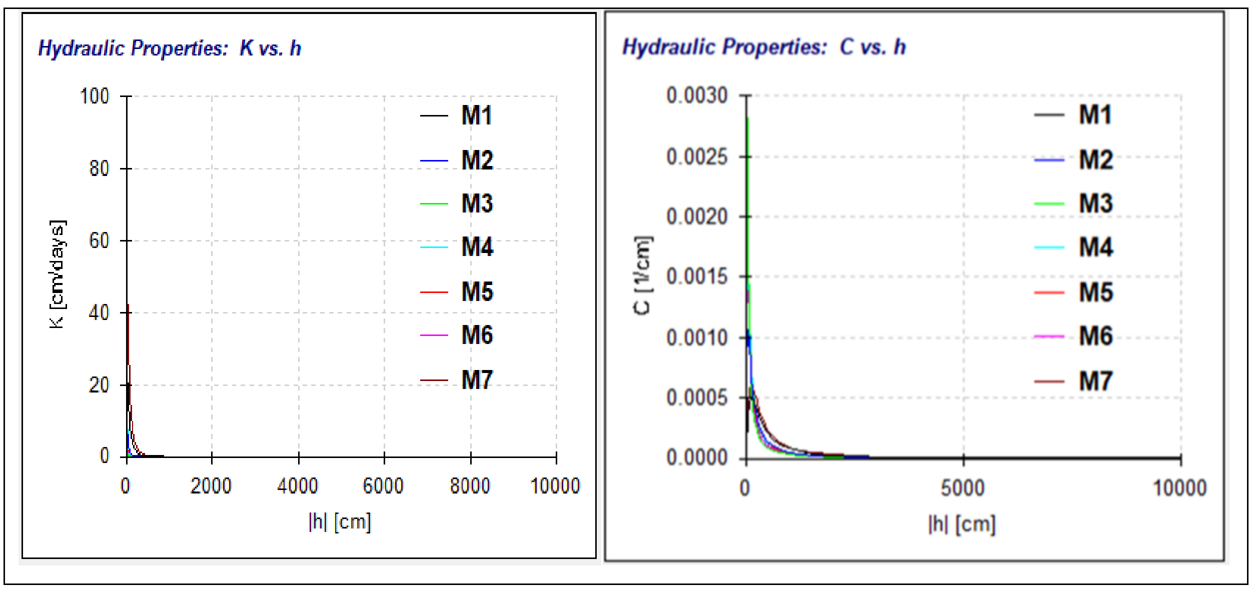


Figure 4. 6 Temporal variations of annual recharge at the Edo watershed (1990-2020)

4.2.2. Hydraulic Capacity and Conductivity Function

The hydraulic conductivity is one of the important hydraulic parameters in process of groundwater recharge, and in this particular study, the hydraulic conductivity and capacity depend on the types of soil and depth. The average hydraulic conductivity for the silt loam soil under study was found as 97.92, for sandy loam 52.23cm day-1, and for loam soil, it was 39.7 cm day-1. The difference is that when the pressure head increases the hydraulic conductivity decreases in the soil profile. The figure 4.8 show a comparison of unsaturated hydraulic conductivity and capacity of silt loam, sandy loam, and loam. The unsaturated hydraulic conductivity decreases with an increase in pressure head for silt loam, sandy loam, and loam. As the pressure head decreases, unsaturated hydraulic conductivity increases gradually see (figure 4.7). The curve is steeper for silt loam soil and flatter for loam soil see (Figure 4.8). At higher pressure head all soils have the almost same value of unsaturated hydraulic conductivity. Because water content is much less at higher pressure heads. For the same pressure head, unsaturated hydraulic conductivity is more for silt loam soil. It shows depth increases the hydraulic conductivity becomes low. In the unsaturated zone, larger pores drain more readily than smaller ones see (Figure 4.8).

Unsaturated soil hydraulic conductivity controls water movement (Fatehnia *et al.*, 2014). In this study, hydraulic conductivity values were obtained from the Hydrus-1D model the observation of unsaturated hydraulic conductivity has different values in soil profile see Table (4.5). The soil types in the profile are silt loam, loam, and sandy loam see (annex 1.4); among those silt loam has high hydraulic conductivity compared with loam, and sandy loam this is why the hydraulic conductivity decreases in the depth.



M-is materials$M_{1,} M_7 - (silt\ loam), M_2 - (\ loam), and M_3 M_4 M_5 M_6 - (sand\ loam))$

Figure 4. 7 K vs h graph and C vs h graph of the soil profile

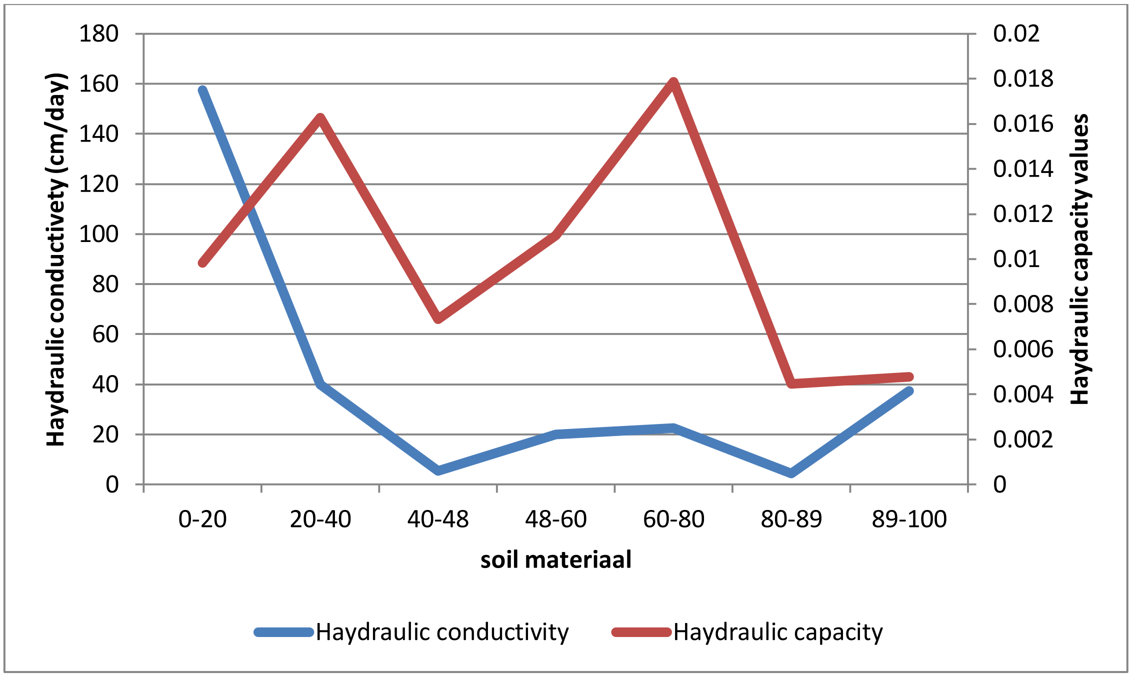


Figure 4. 8 Comparison between Unsaturated hydraulic conductivity and capacity of silt loam, sandy loam, and loam soils.

Table 4. 5 Soil Hydraulic capacity and Hydraulic conductivity

Depth(cm)	Hydraulic conductivity(cm/day)	Hydraulic capacity(1/cm)
0-20	157.472	0.010
20-40	39.790	0.016
40-48	37.457	0.007
48-60	22.441	0.011
60-80	19.926	0.018
80-89	4.428	0.004
89-100	5.391	0.005

4.2.3. Evapotranspiration (ET_o) estimation

The evapotranspiration (ET_o) of the area is computed by the Hydrus-1D version 4.17 model (Simunek et al., 2013), which uses the Penman-Monteith formula to calculate ETO from temperature (minimum & maximum), wind speed, solar radiation, and relative humidity data. Table 4.6 shows the calculated evapotranspiration in Hydrus-1D. As can be seen from Table 4.6, the lowest ET_o was obtained in July and it was about 1.26 mm/day or 39.04mm/month; while the highest ET_o occurs during February and was about 1.1 mm/day or 33.544mm/month. The average ET_o of the area was calculated as 1.11mm/day or 34.44mm/month. The average annual ET_o of the area was 409.43 mm.

Table 4. 6 Eto and Rainfall of study

Month	Rainfall(mm)	ET_o(mm/month)	ET_o (mm/day)
January	40.1	14.714	0.5
February	24.3	33.544	1.1
March	94	45.487	1.5
April	145.2	48.555	1.6
May	154	50.507	2
June	106.9	44.178	1.4
July	169.6	39.04	1.26
August	102.6	38.674	1.25
September	174.5	33.818	1.1
October	151.9	32.585	1.05
November	46.1	20.668	0.67
December	9.1	11.46	0.37
Average	101.53	34.44	1.11

In general, evaporation is most important to evaluate groundwater recharge and it depends on the season when is the rainy season or dry season refer to Figure (4.6) and Figure (4.9).

Figure 4.10 shows the pressure head profile, which represents the condition after a wet and a dry period respectively. A much higher flux following the wet period, and almost zero along the dry period. Near the surface, the downward (negative) flux reflects infiltration due to precipitation, However, below a depth of 100 cm, there is a small positive upward flux from the constant head boundary (the water table) to the soil profile. Note the zero-flux point at a depth below 100 cm, which means at the groundwater table there is zero pressure and at the surface also zero pressure head.

Figure 4.11 shows the soil moisture content with different soil types. Note that the soil types in profile have soil water holding capacity show difference and it depends on precipitation (irrigation) amount, thus promoting this phenomenon.

Figure 4.12 shows the actual surface flux (infiltration minus evaporation) is negative (downward) and represents infiltration, the actual bottom flux is negative and represents recharge. Figure 4.13 shows the soil water storage capacity is shown as the total amount of water that is stored in the soil. A deeper depth means there is a more volume of water stored in the soil. In this particular study, the soil water holding capacity can determine by the types of soil means soil texture is helpful, and also the soil profile.

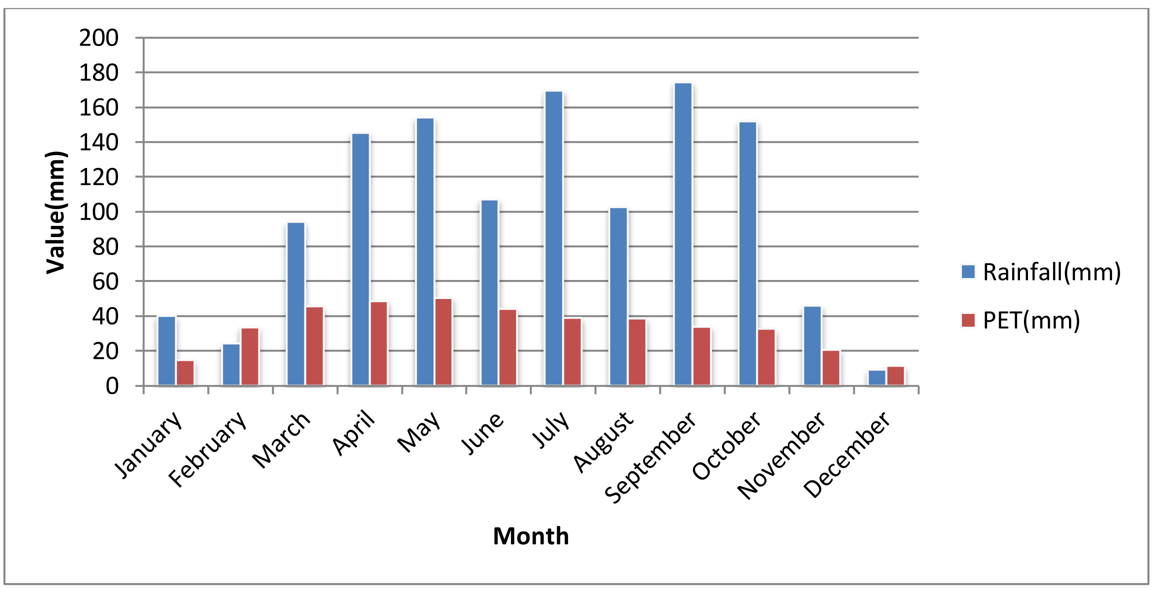


Figure 4. 9 Monthly rainfall and potential evapotranspiration of the watershed in 2020

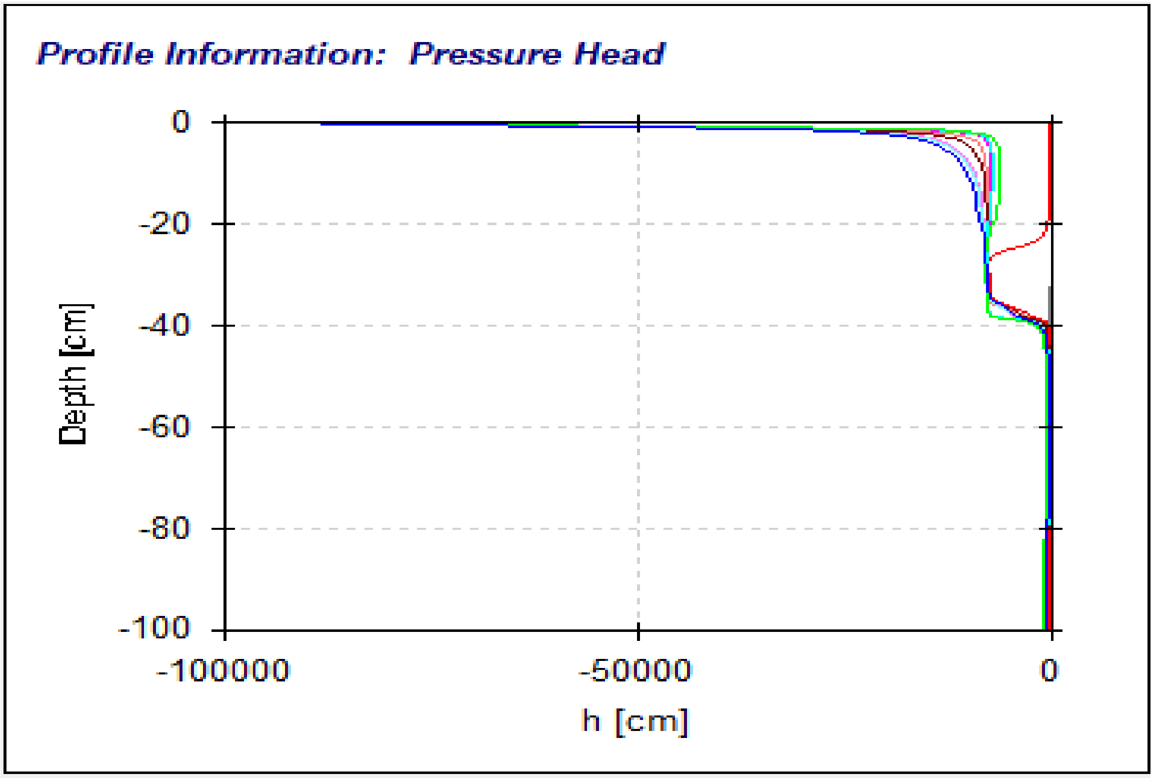


Figure 4. 10 Pressure head profile at versus depth.

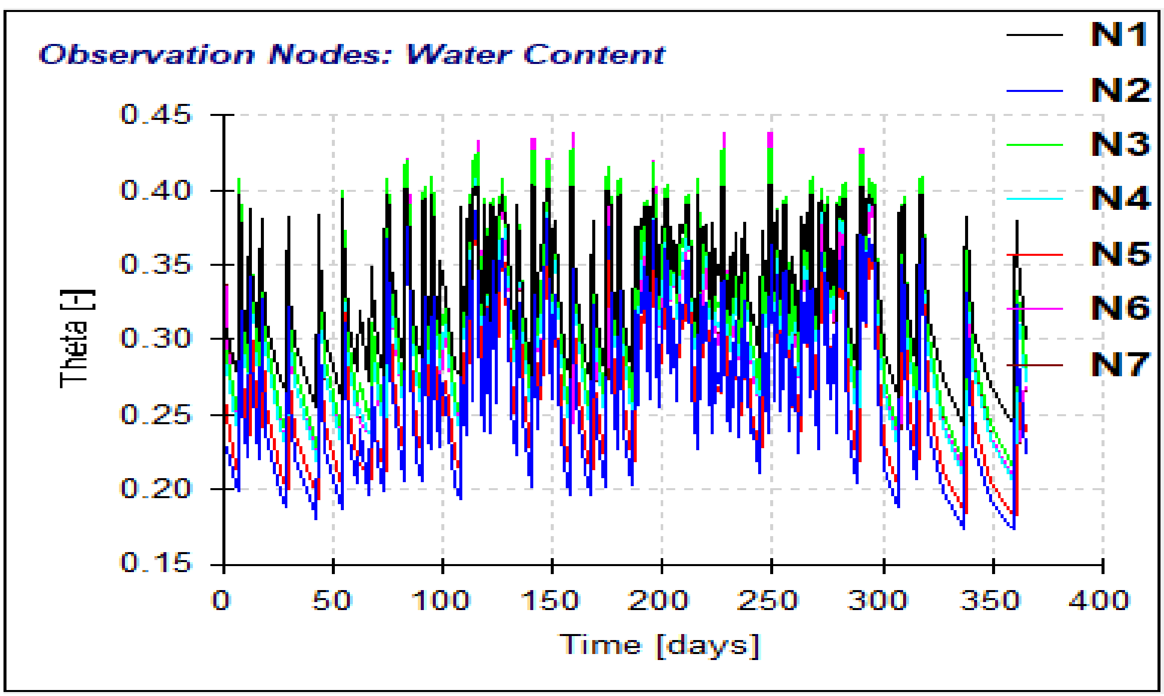


Figure 4. 11 water content in soil profile versus time

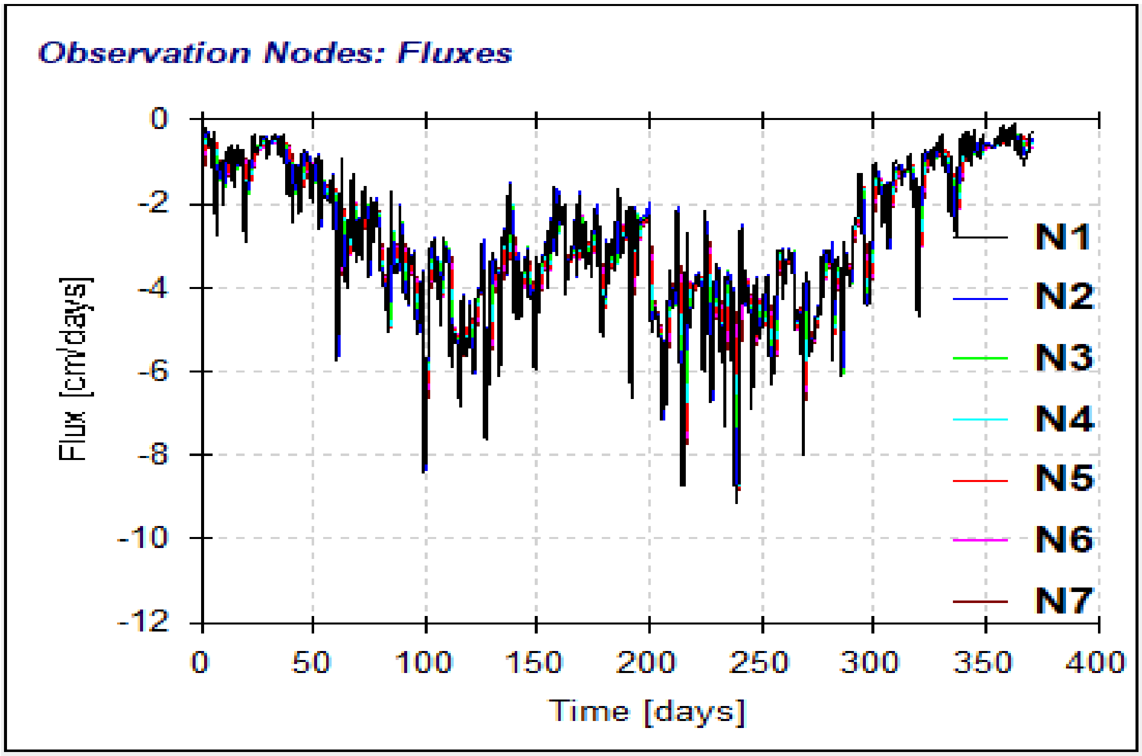


Figure 4. 12 Actual surface flux (into the soil profile) versus time.

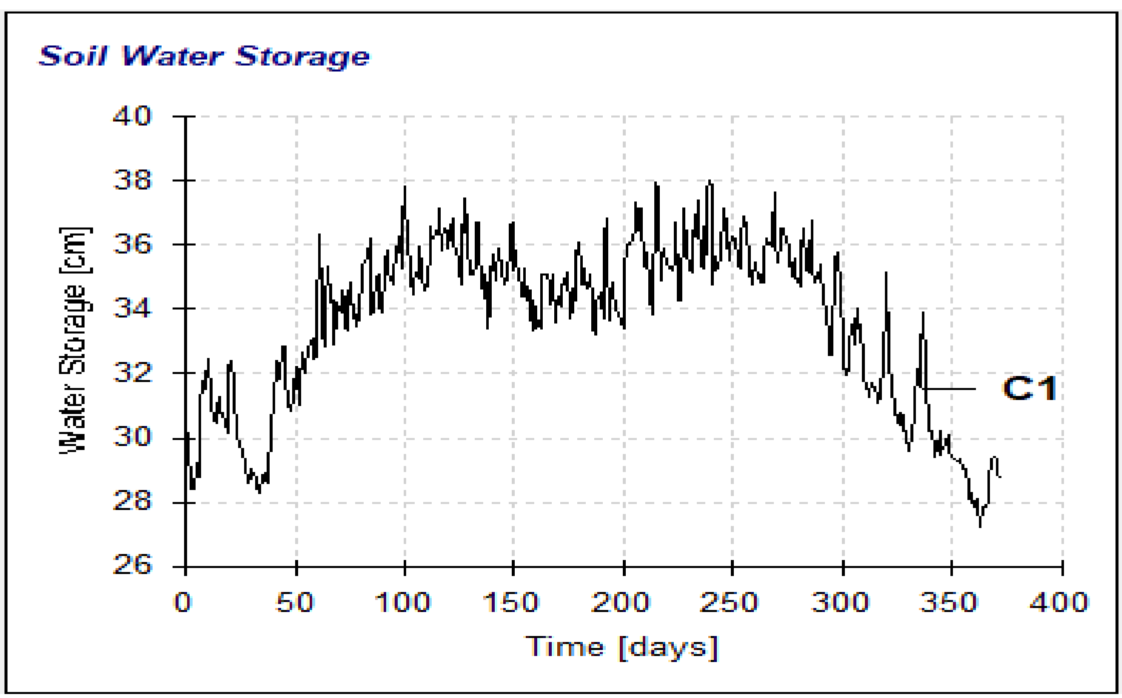


Figure 4. 13 Soil water storage versus time

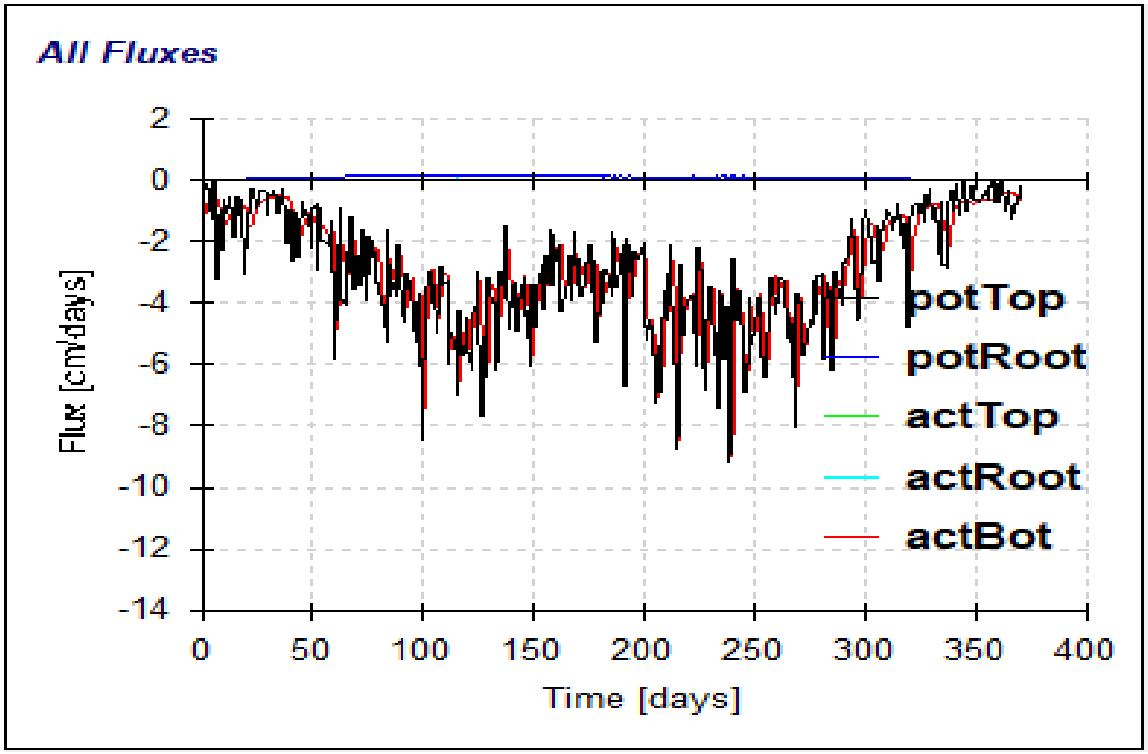


Figure 4. 14 All metrological Flux

4.2.4. Recharge calculation using the WTF method

Based on (Patse, 2018), the specific yield value for the Edo watershed could be taken as 0.1. Indeed, the reference values in the literature were given in wide ranges of specific yields according to the soil textures in the watershed. The lack of soil data of the watershed, and the high cost for the test to derive adapted in situ data make standard values from literature had to be used. Based on recent findings and characteristics of the watershed the average area that contributes to the recharge was assumed as 45 % of the total watershed area and the remains are used for other generations. As a result, the area used for groundwater recharge in this study watershed was $0.45*13348600m^2$, which yields $6006870m^2$.

According to field observation monitoring well the aquifer properties depend on the amount of rainfall and the season. During the rainy season, the amount of groundwater recharge to the water table increases and it raises the water table, but during the dry season the water table fall. The water level fluctuations in the monitoring wells showed that the water levels rose and fell according to rainfall events until the end of the rainy season where in the absence of input of water, the water level shows fell.

The change in the water level reading reached a maximum during the rainy season, but during the dry season, there was no such significant monthly change in the water level. During the dry season, the depth of water in the well tends to increase from day to day and the change in the level became negative. However, during the wet season because of the recharge contribution the water level in the wells increases and the depth of water decrease, as a result, the change in water level become positive.

These results are consistent with those of others. Alley, (2001) reported that water levels in many aquifers are followed a natural cyclic pattern of seasonal fluctuation, typically rising during the winter (wet season in Ethiopia) and spring due to greater precipitation and recharge, then declining during the summer (dry season in Ethiopia) and fall owing to less recharge and greater evapotranspiration. The magnitude of fluctuations in water levels can vary greatly from season to season and from year to year in response to varying climatic conditions. Changes in groundwater recharge and storage caused by climatic variability commonly occur over decades.

The range and timing of seasonal water-level fluctuations may vary in different aquifers in the same geographic area, depending on the sources of recharge to the aquifers and the physical and hydraulic properties of each. The change in water level was the difference in water level in the well from one monitoring date to the next monitoring date. The other thing which is found in the watershed is during in dry season the consumption of water is increasing, and taking too much water too fast draws down the water in the aquifer and eventually causes a well to less water and even run dry.

The hydrodynamic properties of the aquifer in the study area are, also depend on the topography of the land and discharge. In our case or in the study area the groundwater table is near below the conserved land compared to the hilly side. Farmer use hand-dug well in the study area for small-scale irrigation, washing, and dewatering the cow. Due to the lack of modernized tools to dig the well site the farmer uses the local instrument to pump groundwater also, there is a problem with getting enough water.

The farmer who lives upstream cannot get groundwater due to the deep water table only farmers get groundwater below the conserved land which is a downstream area Farmers get groundwater by digging hand-dug well, so groundwater is a very important resource in rural are and the effect of conservation structure also allowed to raise the amount of groundwater table or recharge the aquifer. In the study area, the monitoring of the water table using different technics recorders shows that the aquifer displays well-identified large seasonal water-level fluctuations due to percolation of water during rain period through the unsaturated zone, and flow from the upstream watershed and abstraction of groundwater for different uses refer (Table 4.7).

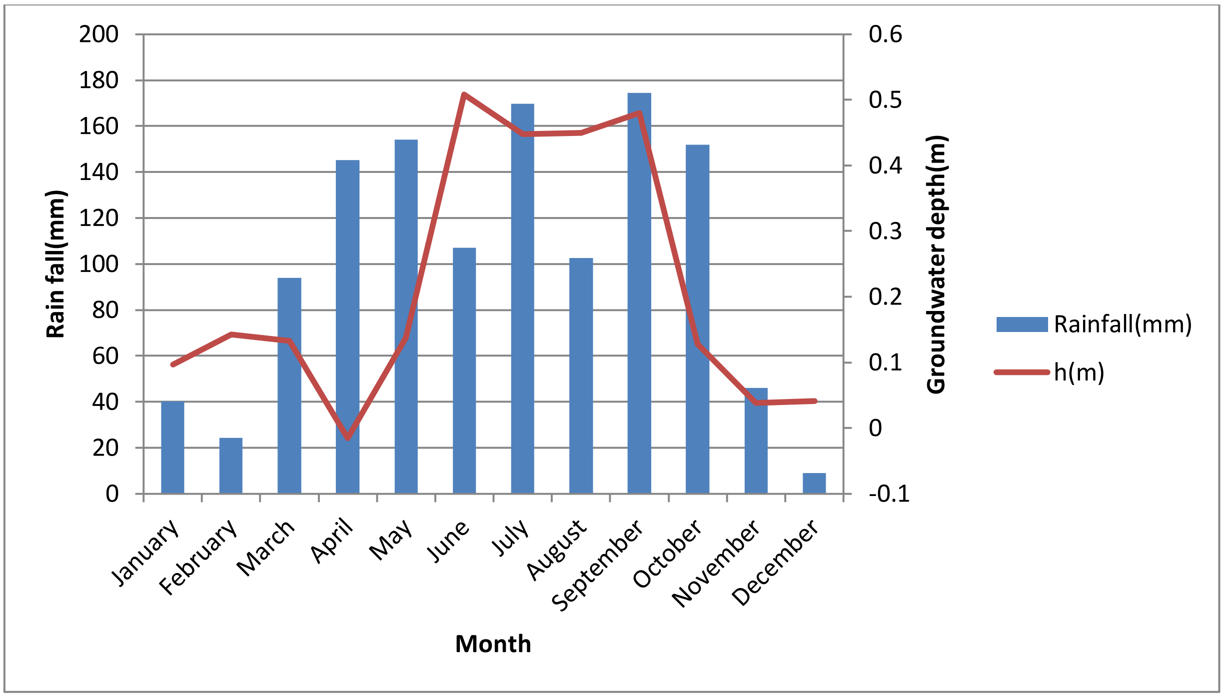


Figure 4. 15 Average well hydrograph, in 2021-2022

The water level in the well was measured from the ground surface. In figure 4.15, groundwater shows starting May up to October shows rising. However, when there is no rain, the depth to water level was dropped the ground this shows in graph October up to April. Because the peak of the rainfall owing to the rainy season occurred in, there was also a low depth of the water during that month, but as the rain starts to decrease it indicates, the depth of water in the well became increased.

In general, the water level decreases during the dry season and when the time of high consumption occurs, and the water depth is high during the dry season and high consumption.

Table 4. 7 Average monthly groundwater recharge for the watershed

Month	Rainfall(mm)	Dh(m)	Sy	A (m^2)	R(m3)
			12+8/2		
Jan	40.10	0.10	0.10	6006870.00	58146.50
Feb	24.30	0.14			85537.80
Mar	94.00	0.14			79867.30
Apr	145.20	-0.02			-9562.94
May	154.00	0.13			82366.20
Jun	106.90	0.50			305197.10
Jul	169.60	0.44			269131.80
Aug	102.60	0.45			269828.60
Sep	174.50	0.48			287993.40
Oct	151.90	0.13			76911.96
Nov	46.10	0.04			22874.16
Dec	9.10	0.04			24556.08

From table 4.7, the amount of water that contributes to the groundwater table during the simulation period was calculated gives 1543765590 $m^{3,}$ or 257 mm. It represents 23.23% of the annual rainfall. The result obtained from the WTF method is smaller than the recharge estimated by the Hydrus-1D method since there was an assumption that 45 percent of the watershed contributes to groundwater recharge. In the study area, the monitoring of water table recorders shows that the aquifer displays well-identified large seasonal water-level fluctuations due to percolation of water during the rain period through the unsaturated zone, and abstraction of groundwater for different uses see Table (4.8).

Table 4. 8 Groundwater recharge values of research wells

Well ID	Location	Recharge(m/year)	Recharge(mm/year)
Well-1	Edo	0.20	191.58
Well-2	Edo	0.20	176.25
Well-3	Edo	0.14	130.58
Well-4	Edo	0.24	239.16

Well-5	Edo	0.31	307.91
Well-6	Edo	0.27	272.41
Well-7	Edo	0.17	159.00
Well-8	Edo	0.25	248.75
Well-9	Edo	0.24	237.58
Well-10	Edo	0.33	330.00
Well-11	Edo	0.36	363.33
Well-12	Edo	0.29	290.00
Well-13	Edo	0.28	264.00
Well-14	Edo	0.27	272.08
Well-15	Edo	0.40	365.16
Well-16	Edo	0.21	210.00
Well-17	Edo	0.27	273.00
Well-18	Edo	0.25	247.00
Well-19	Edo	0.28	239.00
Well-20	Edo	0.29	269.00
Well-21	Edo	0.14	132.75
Well-22	Edo	0.27	259.00
Well-23	Edo	0.38	378.00
Well-24	Edo	0.27	274.50
Well-25	Edo	0.31	300.91

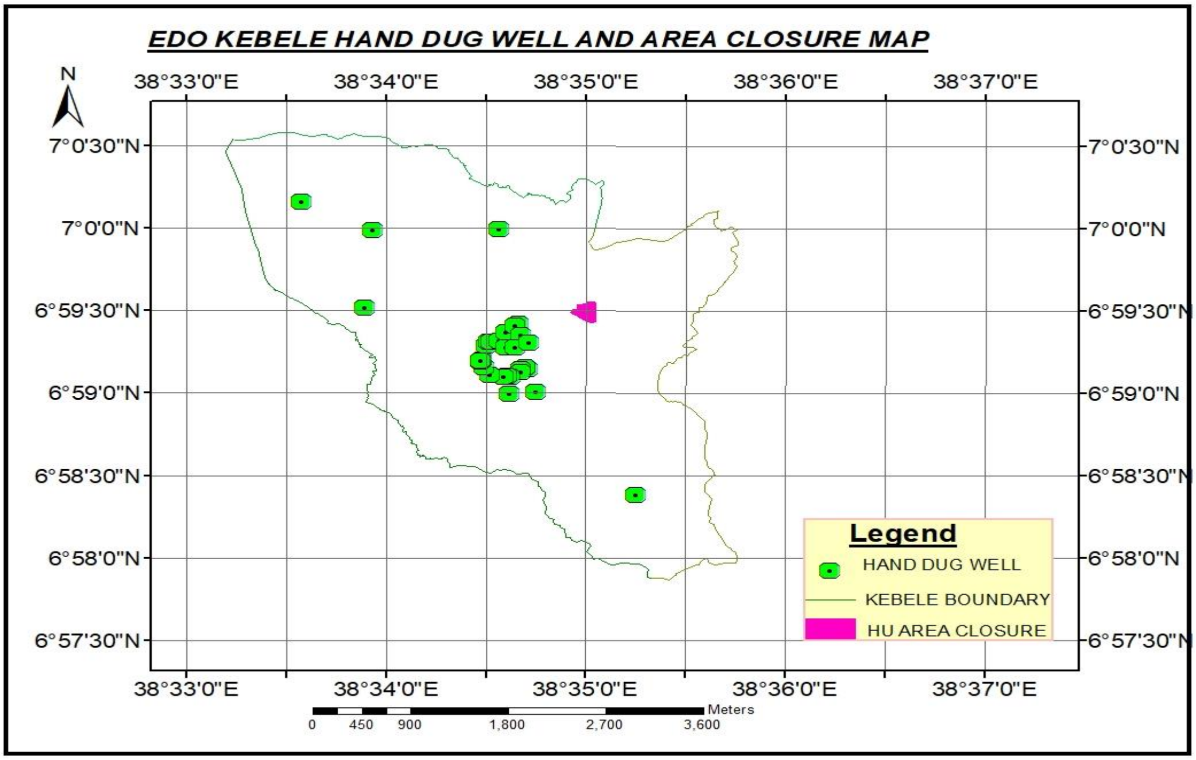


Figure 4. 16 Location of monitoring wells

4.3. Effects of conserved land on soil water

As the result of the conducted field study in the watershed, the dynamics of soil moisture where conserved land (CL) and bare land (BL) was measured. The figure (4.17, 4.18, and 4.19) show the difference between measured and calculated soil moisture and shows the distribution of soil moisture in the field and calculated Hydrus-1D for both CL and BL. During the 2021 simulation period, the result demonstrated that CL (treated site) stored more water content in the soil system compared with BL (untreated site), even during the rainy or dry period which is shown in the below the Figure 4.17.

The soil water contents at the 40 cm soil depth for the CL were higher compared to the BL during the simulation period. This clearly indicated that CL has the potential to conserve soil moisture due to the effect of conservation structure on the soil surface producing less evaporation and delaying the drying of soil moisture. This result is consistent with others, Li et al., (2011) and Liu et al., (2010), reported that the distribution of soil water content in the soil is a function of many factors such as antecedent moisture content, precipitation (irrigation) amount, weather conditions, and land use. Interestingly, the measured soil water content at 40 cm soil depth responded positively to modeled values. Both measured and simulated Soil water in the conserved land (CL) and bare land (BL) in the study watershed responded well to input rainfall events (Figure 4.18 and Figure 4.19). Based on the t-test equal variance statistical analysis result of observed soil water content for CL and BL of 2021 simulation period have a significant 95% confidence level. The difference detected was statistically significant. Due to conservation measures in conserved land, they store more water than the bare land. The soil water content is less in BL compared with CL, because in BL there is no conservation structure both biological and physical, due to this they increase the evaporation and soil erosion which can also cause runoff. Generally, in CL there is a good correlation between R, RMSE, and MBE values compared with BL refer to tables 4.9 and 4.10.

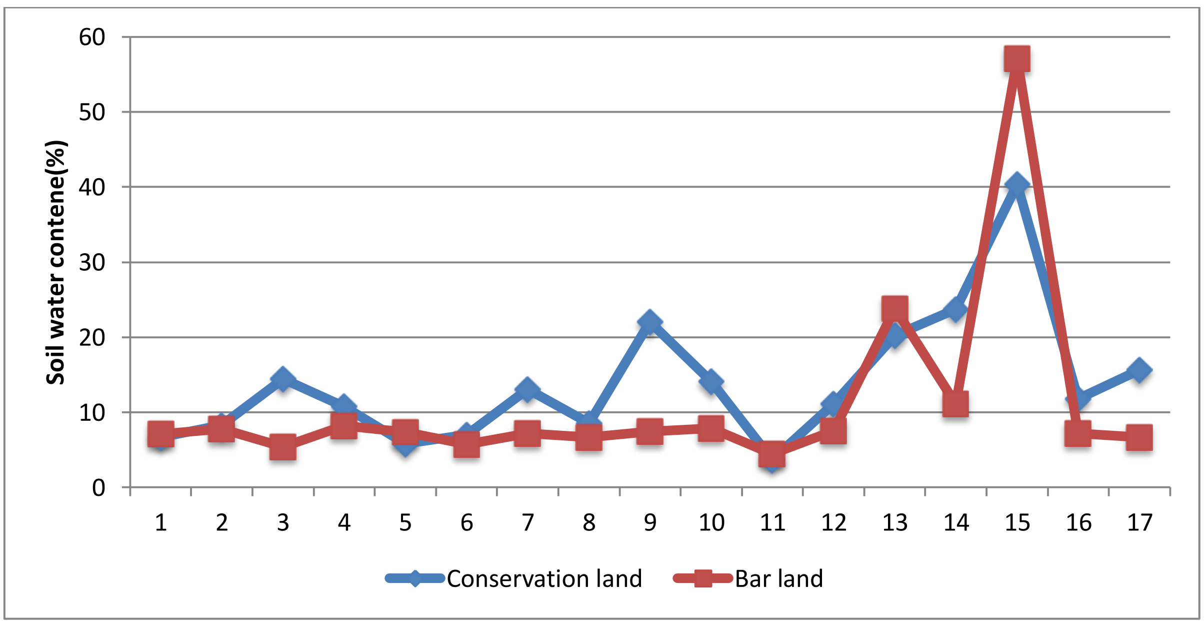


Figure 4. 17 Measured soil moisture in conserved land and bare land at Edo watershed at 40cm depth (2021) in the study site.

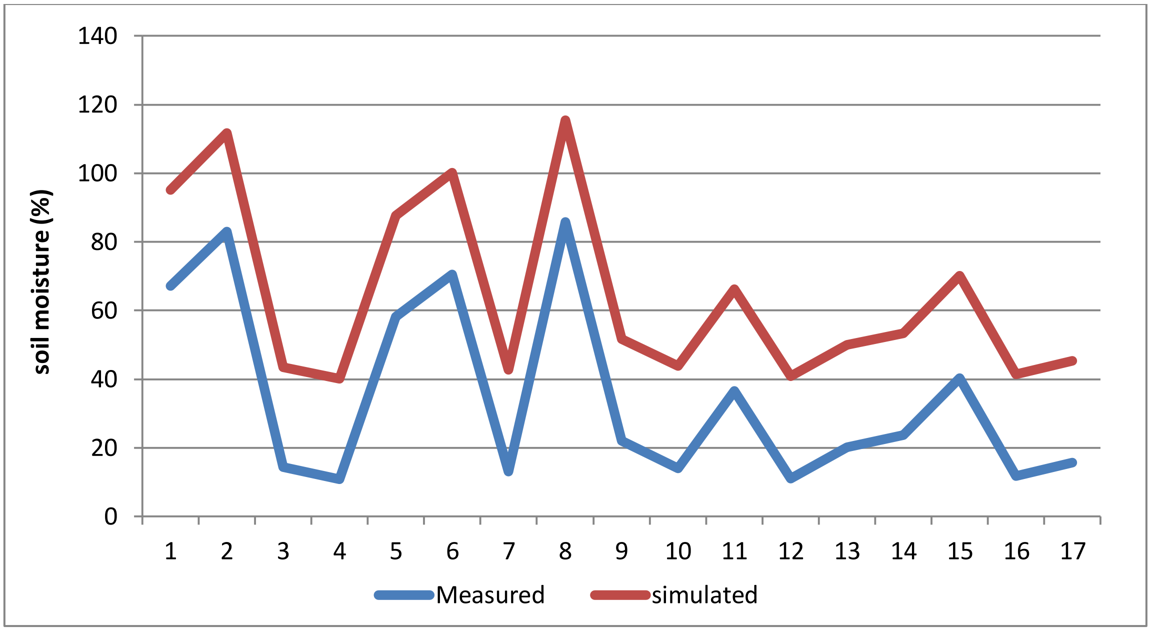


Figure 4. 18 Simulated versus measured soil moisture in conserved land at the Edo watershed at 40cm depth (2021)

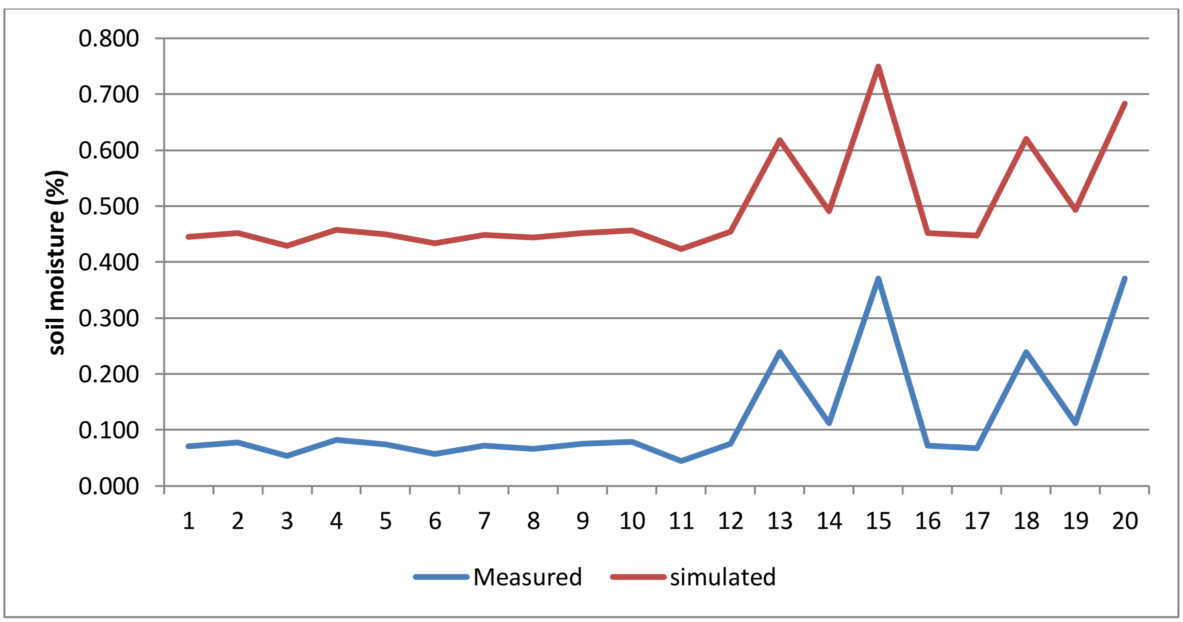


Figure 4. 19 Simulated versus measured soil moisture in bare land at the Edo watershed at 40cm depth (2021)

Table 4. 9 Measured versus simulated soil moisture in conserved land at the Edo watershed

Depth(cm)	R^2	RMSE	MBE
	Soil moisture (cm^3/ cm^3)	Soil moisture (cm^3/ cm^3)	Soil moisture (cm^3/ cm^3)
40	0.9991	0.236	0.057299

Table 4. 10 Measured versus simulated soil moisture in bar land at the Edo watershed

Depth(cm)	R^2	RMSE	MBE
	Soil moisture (cm^3/ cm^3)	Soil moisture (cm^3/ cm^3)	Soil moisture (cm^3/ cm^3)
40	0.939001498	0.282	0.2341

4.4. Impact of Soil and Water Conservation Measures on Groundwater recharge

Land management programs in the study area use both biological and physical land management practices. From this management practices widely used in both land management methods in the study area include the Application of inorganic fertilizer, intercropping, mixed cropping, crop rotation, tree planting, soil bunds, stone bund, check dam, and traditional ditches **(**boyi**).**

4.4.1. Biological land management practices

4.4.1.1. Manure

Manures (dry animal wastes) combined with straws that are remnants of plants used for animal fodders are important to land management practice. Manure also includes the byproducts of local food production processes like atela (the by-product of local brewing) and others, which are daily swept out of a house in dirt forms (Tadesse, 2011). According to survey results, I get (35.3%) in order to improve the fertility of the soil and protect against soil erosion however Wondmagegn (n.d) gets (37.83%), the difference is due to the farmer's use of soil bund and tree planting than manure this is because some NGO and government help the farmers through the agricultural office. However, farmers used manure mainly to farm plots that are near the homestead.

Manure application is the first used method of soil improvement next to mixed cropping and planting trees and intercropping. Contrary to this finding, Shiferaw, *et al.* (1998) reported that farmers use manure to improve the fertility of the soil and protect against soil erosion.

4.4.1.2. Crop rotation

Survey results revealed that about 5.40% of the respondents have applied crop rotation as a conservation measure. Crop rotation is mainly a common practice exercised by many farmers as compared to other practices both moderate to low slope conditions for soil fertility maintenance, weed, and disease control. The sequence of rotation is not similar in all agroecology, because it depends on the crop grown in the area.

4.4.1.3. Tree planting

Tree planting is used as the conservation structure in the study area. In surveying, the result shows that (43.71%) is farmers use tree planting to reduce soil erosion and runoff in degraded land. In addition to degraded land, the farmer uses tree planting in a sloppy site that helps the roots of trees hold the soil in place as it reduces erosion that causes soil erosion. It also absorbs and stores rainwater that helps reduce runoff and sediment deposits after the storms. It also helps recharge groundwater supply, prevents the transport of chemicals, and prevents flooding.

As the survey, the result indicated Respondents from the Edo watershed, reported they planted trees around cropland areas and fruits like Papaya, mango, banana, and avocado plantations. This may be due to better access to information about the importance of agroforestry practices and accessibility of market opportunities. The other issues concerned with tree planting are economical values in the watershed. As a result of this, the informants in the Edo watershed reported that they were beneficial from such agroforestry practices to earn extra cash income.

The high-value tree species, Avocado (Persia Americana) and grevillea robust were evaluated for their performance to be integrated as boundary plants. In general, the study revealed that the use of tree planting as a land management practice in the watershed has a positive impact on the soil and water conservation system by increasing the soil moisture in the soil and reducing runoff (refer to section 4.3).

4.4.2. Physical land management practice

In the study area farmers next to the biological conservation measurements used physical conservation measurements. These physical measurements at the study area are soil bund, stone check dam, soil bag Gabion check dam, and traditional ditch (boy).

4.4.2.1. Soil bund

During discussions with key informants in the study areas, the farmers mentioned that ineffective designs by the development agents are responsible for causing gullies. Farmers use mostly soil bunds that are impermeably intended to maintain all rainfall but when overtopped at one location cause gullies unless they have specially designed spillways. Farmers use simple hand (local) tools for construction and the design of the structures is made following the contour line.

The depth of the bund was in the range of 30-50cm, and spacing between successive furrows depends on slope and crop type. It requires little technical input and also minimal time and construction labor, especially when using an oxen plow. However, the disadvantage of this structure as explained by the farmer in the study area it requires a lot of maintenance in a short period due to being filled with soil immediately after heavy rainfall and did not allow oxen plow.

It is mainly implemented on cultivated land with slopes in the range of 8% to25%, but also on grazing land with gentle slopes at wider intervals (Lakew *et al.* 2005). It is constructed to control runoff and erosion from cultivation fields by reducing the slope length of the farm which ultimately reduces and stops the velocity of runoff. These structures are effective in controlling soil loss, retaining moisture, and eventually enhancing the productivity of the land. These structures were installed at a vertical interval (VI) depending on the slope of the land and the size of the ditch can be 0.5m deep by 0.5m wide at the beginning of the bund length of 10 m.

Figure 4. 20 Soil bunds at the study area

4.4.2.2. Stone check-dam

According to key informants and fieldwork, the structures have similar characteristics in terms of Effect, purpose, and time of construction with that of soil bunds. However, Stone check dams are permanent and less durable structures constructed on gentle and steeper slopes. Small and medium-sized stones are the main materials required for the construction of these structures. In the construction of a Stone check dam, the passage of water through a layer of stone is controlled by applying fine soil in between stones.

Figure 4. 21 Stone check dam on land affected by soil erosion

4.4.2.3. Soil/sandbag Check-Dam

According to in FGDs with farmers and key informant interviews with reported that a Sandbag check dam was constructed three years ago in the study area. One bag contains (50 kg) filled with soil and the bags are piled up to a maximum of 2 layers to form a small check dam. This cheap technique is particularly useful in an area with an insufficient supply of stones for building ordinary check-dams. However, sandbag dams have not controlled gully erosion in the study area, and they are not suitable for the treatment of large gullies.

Figure 4. 22 Soil bag check dam

4.4.2.4. Traditional ditches (boyi)

According to FGD farmers and key informant interviews with development, agents reported that this is the most important land management practice prevailing in the area. The design of the structure is done by cutting ditches down the slope on both sides and sometimes also along the upper boundary. For its construction and maintenance, simple local tools such as hoes and spades are used, and also it requires little or no technical input. Are used to drain excess water from farmlands during high rain time, especially in July and August, and do most of the time by hoes and spades.

The respondents reported that traditional ditches are constructed every cropping season and run diagonally over the cultivated land. Depending upon the slope gradient of the farm plots, farmers make ditches with a certain interval. The distance between two consecutive ditches decreases with slope gradient. However, the distance is not based on the scientific measurement and varies from plot to plot. The main purpose of the traditional ditch is to protect the soil from waterlogging. Sometimes farmers make ditches to drain water from flat fields during the long growing season. The main advantage of traditional ditches is that it takes less time and can be made by hoes and spade, hence, it requires less time and labor as compared to other conservation measures.

Figure 4. 23 Traditional ditches

4.4.2.5. Gabion check dam

Wondo Genet Woreda Edo watersheds practice one kind of wood gabion conservation measurements from physical land management. In the study area (2021-2022) wood gabion land management measurements were undertaken help of Hawassa University. These conservation structures more affect structures than others before implementing structures. Key informants thought that these conservation structures more rehabilitate degraded land than physical land management practices such as soil bund, stone cheek dames, soil/sandbag check dams, and traditional ditches because the structure is constructed according to the scientific standard, but the other one is constructed by farmers and not follow the scientific standard as assessed in the field. Additionally, respondents as wood gabion check dams are an important conservation method for controlling gully erosion compare with above mention land management practices. Furthermore, they are somewhat flexible and can be installed where the surface is uneven. If the slope gradient increases the interval between gabion decreases and vice versa is true.

Figure 4. 24 Wood gabion check dam at the study area

4.4.3. Estimation of the intensity of conservation structures

The intensity of Conservation Structures is the most important factor to establish the relation of Groundwater Recharge with conservation structures. The intensity of Conservation Structures was calculated with the help of the given formula. The intensity of all conservation structures estimated in each Edo watershed shows that the Gabion check dam has a high contribution to groundwater recharge compared with other conservation structures. The next Gabion check dam trench is also good for the contribution of groundwater recharge compared with other conservation structures refer to Table (4.11).

Table 4. 11 Intensity of Total Conservation Structure

No	Name of Structures	Intensity (per Km^2)
1	Soil bund	0.135
2	Gabion check dam	0.34

3	fanaju	0.07
4	Stone check dam	0.09
5	Soil/sand bag check dam	0.0898
6	Trench	0.224

Table 4. 12 Number of structures and intensity

Name of Structures	No of structure	Intensity
Soil bund	300	0.1348
Gabion check dam	750	0.337
Fanaju	150	0.067
Stone check dam	210	0.094
Soil/sand bag check dam	200	0.0898
Trench	500	0.224
Total	1435	

Land management practices in the study are assessed with different technics to evaluate the impact of land-use change in hydrology. From observation conservation structure constricted in the watershed have a positive impact on soil moisture and groundwater recharge. The measured soil moisture in reclaimed land and bare land shows the difference in moisture content. Figure 4.25 represents the accumulated soil moisture content for different scenarios during the simulation period 2021 and shows that measures of soil and water conservation might lead to a great proportion of rainfall being infiltrated and available for groundwater recharge. Conserving the soil surface with conservation measures is an effective method of conserving water because it reduced surface runoff, increased the infiltration of water into the soil, and retarded soil erosion. Soil water content in the conserved land scenario is more compared with a bare land scenario. Based on the calibrated numerical model Hydrus-1D, from average annual rainfall, groundwater recharge increases by 11.23 % after conservation measures.

When comparing this result with that of others. Wang, (2014) reported that measures of soil and water conservation (SWC) could affect the hydrological process, and water conservation measure increases groundwater recharge by reducing runoff in a different scenario. The impacts of typical measures on groundwater recharge, levels, and flow were analyzed based on simulated rainfall experiments and a groundwater model. It was concluded that SWC measure construction would increase groundwater recharge and the measure destruction would decrease recharge (Wang, 2014). Unsaturated-zone results suggest that land-use impacts on diffuse recharge strongly differ between ecological and structural approaches to soil conservation in the study area. Results suggest that cultivated agricultural land use maintains deep drainage rates of approximately 11–18% of mean annual rainfall. The results of this study emphasize the potential for impacts of soil conservation on groundwater resources, which is relevant globally considering the scale of agricultural soil loss.

For the Loess Plateau, they also indicate that there is an opportunity for achieving a better balance between erosion mitigation and water-resource sustainability goals by diversifying conservation approaches (Gates, 2011).

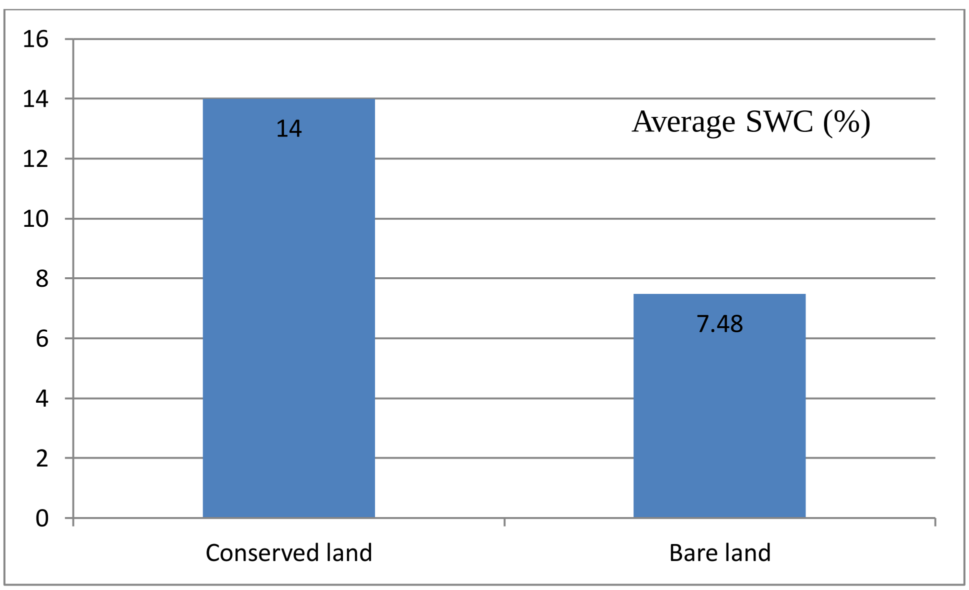


Figure 4. 25 Average measured SWCs of CL and BL during the 2021 simulation period.

5. SUMMARY AND CONCLUSION

5.1. Summary

Groundwater study is vital for the development of groundwater resources and optimization of groundwater use in all respect. Groundwater was used many years ago for different purposes like recreation, drinking, fore domestic purposes, and irrigation throughout the world. Groundwater is the purest form of water compared with surface water, and it needs a little treatment compared with the other form of water. Over the years, it has continued to play a major role in augmenting the existing water supply to meet the requirements and increasing demands for agricultural, domestic, and industrial use. To assure the water supply to the growing population under human activities, changes in climate variability, growing demands, and catchment degradation, groundwater recharge investigation is one of the main concerns for water managers in the coming decades.

The conservation methods of the groundwater recharge are an important scenario, and groundwater recharge by controlling water loss in runoff and soil erosion is essential for sustaining the water resource in the watershed. Recharge is primarily determined by precipitation. The incoming precipitation may be intercepted by plant canopies and evaporates back into the atmosphere. Part of the precipitation that reaches the ground may be stored in depressions, infiltrate the soil, and/or runoff depending on the rainfall intensity and land cover.

The overall objective of this study is to assess the impact of land management practices on groundwater recharge Edo watershed by using Hydrus-1D and water table fluctuation methods. More specifically the evaluation of groundwater recharge by using Hydr-1D, and WTF methods, the applicability of Hydrus-1D in the study area, the effects of conserved land on soil water content compared with bare land, and asses impacts of land management practice on groundwater recharge.

The vadose zone hydrological model Hydrus1-D and water table fluctuation methods were used to estimate the groundwater recharge using, climate data, soil data, and groundwater well data in 2021-2022 for WTF. Sensitivity analysis, Calibration, and validation were done by using measured and simulated soil moisture data and soil parameters to check the performance of Hydrus-1D in the analysis of ground water recharge. Cross-validation of the result showed minor differences between modeled and measured soil moisture and soil parameters to run the model, but a major difference between CL and BL soil was observed.

The result of the conducted field study in the watershed, the dynamics of soil moisture where conserved land and bare land were measured. During the 2021 simulation period, the result demonstrated that CL (treated site) stored more water content in the soil system compared with BL (untreated site), even during the rainy period. The soil water contents at the 40 cm soil depth for the CL site were higher compared to the BL site during the simulation period. Due to a lack of reliable data related to groundwater in the watershed used only one year of water level data to estimate recharge by using the WTF method in 2021-2022.

In the first Hydrus-1D and WTF methods approach, the effect of conservation measures on groundwater recharge in the Edo watershed was shown to increase the amount of recharge. Fluctuations in groundwater table depth were examined from 2021-to 2022 in twenty-five observation wells. The rainfall and climate data were taken from NMAE and water level data were collected from 25 hands dug well in selected farmers. The overall hydrograph of the water level in the watershed was depending on the seasonal fluctuation. However, the observation wells located below the CL systems revealed a greater resistance to dry periods and extractions than the other wells in the area.

The recharge was calculated by Hydrus-1D was 297.89 mm and 257.1mm by WTF methods, the difference due to the fluctuation of water level in the well. The other things to evaluate are soil moisture content inside the soil from conserved land and bare to know the contribution to groundwater table recharge evaluation processes in observation the amount of water found in the soil is high in conserved land compared with bare land. This can show that the high amount of water storage in the soil contributes to the recharge of the aquifer, the Hydrus-1D model simulates that when more water is inside the soil it increases the recharge of groundwater for the year.

Land management practices in the study area assed in different technics to evaluate the impact of land-use change in hydrology. From observation conservation structures constricted in the watershed have a positive impact on soil moisture and groundwater recharge, and soil and water conservation structures are included for analysis of the impact on groundwater recharge. Before the construction of conservation structures, groundwater recharge rates were depleted, and after the construction of conservation structures, groundwater recharge rates were increased.

The intensity of all conservation structures estimated in each Edo watershed shows that the Gabion check dam has a high contribution to groundwater recharge compared with other conservation structures. The next Gabion check dam trench is also good for the contribution of groundwater recharge compared with other conservation structures. With the calibrated soil parameters, the Hydrus-1D (H1D) model that simulates water content in porous media was employed to evaluate recharge. The results show the reliable and consistent evaluation of each soil layer before the recharge events. The calibrated results show the model is applied in future work in that watershed.

5.2. Conclusion

The overall objective of this thesis work was to estimate groundwater recharge, soil water dynamics, aquifer properties, and the impact of land management practices on the groundwater recharge in the Edo watershed. The vadose zone model Hydrus-1D, which only uses soil information and climate data as input, allows for cost-effective, efficient, and robust recharge estimation. These techniques were applied to enable and asses of the land management dynamic effects on the hydrology of the watershed. The impacts of the land management practices on groundwater recharge were analyzed statistically using the hydrological model, Hydrus-1D. To do this analysis, first land management practices in the study area were analyzed; then the Hydrus-1D model was used for its performance at the Edo watershed in order to examine the hydrological response of the watershed to changes in land management practices.

The study shows that land management practice's use in the Edo watershed was assessed by using questionaries' and checking the soil conservation works in the watershed from 2011 to 2013. On the other hand, data preparation, sensitivity analysis, calibration, validation, and evaluation of model performance were performed on the selected, Hydrus-1D, model. These analyses are done before the evaluation of the impacts of the land management practices on the groundwater recharge of the watershed was analyzed. The ROSETTA was used to calibrate soil hydraulic parameter which is incorporated in mode by using soil physical parameters and displaying the model result. Based on the results, the following conclusions are drawn:

In areas where groundwater is used for small-scale irrigation and domestic purposes, such as the Edo watershed groundwater recharge, which is an essential prerequisite for sound, scientific groundwater management, evaluation is an important tool for quantifying the groundwater amount. The average annual recharge to the rainfall in the study area was estimated by Hydrus -1D to be 297.889mm (26.9% of the average annual rainfall) and 257.1 mm (23.23%) of average annual recharge by water table fluctuation methods.

The Hydrus -1D model analysis led to the conclude that conserved land is most important to store more water in the soil and that is good for the contribution of recharging the aquifer. The sensitivity analysis using the Hydrus-1D model has pointed out the three most important parameters that influence the groundwater recharge of the studied watershed. On the other hand, model calibration and validation have shown that the Hydrus-1D model simulated the recharge in a manner adequate to the requirement. Performance of the model for both the calibration and validation watershed was found to be reasonably good with (R^2) correlation coefficients values of 0.991, (RMSE) root mean square error values of 0.236, and (MBE) mean bias error values of 0.057 for conserved land in the watershed. The applicability of the model is good for conserved land compared with bare land, so the model can be used the future groundwater recharge analysis.

From the soil moisture analysis, it is possible to conclude that land use has its own effect on soil moisture, conserved land has sore more water compared with bare land and the impacts on groundwater recharge are also good by contributing the water to recharge the water table.

The conservation structures constructed in the study are given important value for farmers by reducing runoff and improving crop productivity as well as soil erosion in the watershed. The conservation measure changes the groundwater recharge by increasing infiltration and storing more water in the soil system by reducing water loss from soil by runoff. The conserved land in 2011, 2012, and 2013 increased recharge by 11.23%, compared with before the use of conservation structures in watersheds. In addition to the conservation structure in the study area especially on sloppy land give important value to recharging the aquifer and make the good potential for the groundwater source. Land management practices in the watershed are recognized to have major impacts on hydrological processes, such as runoff and groundwater flow. Generally, conservation practice is to store more water in the soil and reduce runoff; and recommended for farmer land management practices in the study area.

5.3. Recommendations

Compared to bare land conservation practices store high water content in the soil system by reducing runoff. Hence conservation practices increase water infiltration into the soil and it has also groundwater recharge. Recommend that the watershed improve groundwater resources by using different land management practices, especially on the hilly side and on some bare land that has no conservation structure. Further investigation is essential to understand the effect of land management practices on irrigation yield in addition to groundwater recharge. The other thing which is highly recommended is that in the study site there is a lack of data related to groundwater, so the future work will use this study as a source of investigation.

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APPENDICES

Appendices 1. 1 Average daily values of meteorological variables in near Edo watershed

Days	rain fall	T max (oC)	T Min (oC)	Relative Humidity	Wind (km/day)	Sunshine(hr)
1990	0.56	28.39	11.12	48	0.73	8.71
1990	0.11	28.77	10.41	48	0.66	8.97
1990	0.24	28.80	10.47	48	0.72	8.92
1990	0.79	28.71	11.08	48	0.76	8.82
1990	1.26	28.88	11.17	47	0.75	8.90
1990	0.07	28.48	11.31	48	0.76	8.49
1990	3.22	28.85	11.58	48	0.77	8.02
1990	1.24	28.79	10.99	49	0.70	8.36
1990	0.98	28.97	11.46	48	0.74	8.68
1990	2.24	28.93	11.84	49	0.76	8.82
1990	0.62	28.84	11.74	48	0.79	8.73
1990	1.05	28.70	12.23	49	0.81	8.74
1991	0.56	28.91	11.60	49	0.77	8.44
1991	0.90	28.99	11.85	50	0.73	8.25
1991	1.82	28.76	12.08	51	0.72	7.67
1991	0.52	28.84	11.88	50	0.73	7.98

1991	1.11	29.20	12.29	50	0.77	8.58
1991	0.65	29.16	12.44	52	0.79	8.45
1991	0.75	29.00	12.56	52	0.74	8.60
1991	3.01	28.98	11.66	53	0.88	8.88
1991	1.42	28.79	11.83	53	0.77	8.50
1991	1.04	29.28	12.06	52	0.80	9.18
1991	0.28	29.33	12.04	51	0.77	9.45
1991	0.28	29.31	11.72	49	0.70	9.49
1992	0.89	29.42	11.96	49	0.69	9.10
1992	0.66	29.13	12.01	49	0.74	8.43
1992	0.34	29.44	11.83	47	0.72	8.66
1992	0.42	29.75	11.90	49	0.73	9.34
1992	0.43	29.51	12.31	49	0.83	8.54
1992	1.11	29.57	12.25	50	0.85	9.15
1992	0.46	29.47	12.55	50	0.87	9.10
1992	0.48	29.88	11.79	48	0.93	17.85
1992	0.35	29.82	12.14	46	0.79	9.39
1992	0.49	29.93	11.82	47	0.78	9.53
1992	1.02	29.93	11.80	49	0.78	9.20
1992	0.79	30.01	11.85	48	0.76	9.06
1993	0.27	29.97	12.38	48	0.78	9.03

1993	1.28	29.80	12.70	49	0.82	8.60
1993	2.02	29.58	12.83	50	0.78	7.99
1993	0.95	29.19	12.33	49	0.71	7.77
1993	2.59	29.78	12.23	52	0.71	7.95
1993	1.48	29.93	11.99	49	0.73	8.39
1993	1.04	30.22	12.08	48	0.74	8.54
1993	2.45	29.92	12.58	49	0.78	8.70
1993	1.80	30.17	12.28	49	0.78	8.58
1993	0.66	30.18	13.07	50	0.79	8.56
1993	0.77	29.91	12.98	51	0.83	8.07
1993	1.13	29.71	13.24	49	0.78	8.04
1994	1.51	30.05	13.04	49	0.73	8.38
1994	2.17	30.36	12.52	48	0.75	8.56
1994	0.88	30.32	12.20	47	0.78	8.85
1994	0.78	30.48	11.76	46	0.72	8.84
1994	2.92	30.63	11.98	47	0.73	9.10
1994	0.90	30.77	12.39	46	0.82	9.11
1994	1.96	30.67	12.91	48	0.79	8.55
1994	1.81	30.51	12.67	51	0.74	8.17
1994	2.14	30.19	12.83	52	0.73	8.56
1994	2.09	30.59	12.88	48	0.75	8.42

1994	1.32	30.28	12.86	48	0.78	8.29
1994	2.98	30.69	11.66	48	0.73	8.73
1995	5.82	30.59	11.91	50	0.80	8.23
1995	3.32	30.61	12.47	51	0.79	8.44
1995	0.88	30.47	12.87	49	0.77	8.31
1995	3.88	30.32	12.73	50	0.76	8.01
1995	4.07	30.34	12.44	52	0.75	8.31
1995	2.35	30.14	12.67	48	0.69	8.30
1995	2.95	30.47	12.68	48	0.75	8.17
1995	1.22	30.18	13.34	49	0.81	7.94
1995	3.54	30.33	13.28	51	0.80	7.79
1995	2.46	30.07	13.44	51	0.76	7.73
1995	2.51	30.46	13.23	51	0.79	8.39
1995	3.41	30.25	13.38	48	0.78	8.04
1996	1.65	30.36	12.96	49	0.76	8.08
1996	2.36	30.54	13.17	48	0.78	8.33
1996	3.90	30.55	12.94	49	0.75	8.34
1996	1.87	30.25	12.64	50	0.68	8.21
1996	3.02	30.47	13.12	50	0.70	8.38
1996	1.96	30.02	13.45	51	0.75	7.63
1996	2.54	29.83	13.78	53	0.78	7.20

1996	3.36	29.93	14.07	56	0.77	7.84
1996	4.06	29.70	14.14	59	0.73	7.42
1996	4.07	29.88	13.33	55	0.76	7.86
1996	4.29	30.01	13.24	54	0.72	7.61
1996	5.24	30.24	14.02	55	0.72	8.42
1997	1.65	29.97	13.94	56	0.69	7.66
1997	3.75	29.92	13.60	57	0.69	8.06
1997	3.30	29.93	13.71	57	0.65	7.72
1997	3.75	29.88	13.71	56	0.69	7.65
1997	2.10	30.13	13.79	55	0.68	7.99
1997	2.89	29.95	13.58	56	0.70	8.32
1997	4.26	28.90	14.07	59	0.69	7.28
1997	4.60	29.29	14.25	58	0.68	6.76
1997	3.08	29.41	13.94	59	0.73	6.92
1997	3.54	29.50	13.87	57	0.70	7.64
1997	3.25	29.69	14.00	55	0.70	7.34
1997	4.58	29.52	13.72	57	0.69	7.05
1998	5.23	29.62	14.04	58	0.73	7.39
1998	4.26	28.89	14.02	61	0.65	6.91
1998	3.71	28.82	14.34	60	0.66	7.05
1998	8.48	28.82	14.40	62	0.70	6.42

1998	5.84	29.12	14.26	61	0.68	7.17
1998	3.87	29.38	13.95	61	0.65	7.61
1998	3.01	29.55	13.79	59	0.69	7.42
1998	2.95	29.54	13.80	61	0.73	7.28
1998	3.99	28.63	14.41	60	0.62	6.54
1998	3.41	28.08	13.99	64	0.65	6.68
1998	4.98	28.18	14.67	63	0.71	6.30
1998	3.75	28.72	14.41	60	0.65	7.43
1999	2.82	28.50	14.40	61	0.73	6.92
1999	3.39	28.67	14.16	60	0.68	7.21
1999	3.29	28.79	14.25	61	0.76	7.51
1999	6.00	28.47	14.89	62	0.71	6.38
1999	4.95	27.83	14.84	66	0.62	5.94
1999	5.36	28.81	13.94	64	0.68	7.29
1999	5.49	28.59	14.41	63	0.68	6.87
1999	6.94	28.58	14.58	63	0.68	7.65
1999	4.28	28.00	14.27	66	0.63	6.09
1999	5.72	28.23	14.63	63	0.69	7.13
1999	5.41	28.37	14.76	65	0.71	6.71
1999	4.47	27.87	14.88	64	0.69	6.28
2000	5.59	28.08	15.08	68	0.63	6.50

2000	6.17	28.21	14.64	66	0.68	6.28
2000	4.53	28.38	14.80	65	0.66	6.34
2000	4.13	27.55	13.44	64	0.75	5.46
2000	4.26	28.01	14.51	66	0.66	7.10
2000	3.01	28.29	14.67	65	0.76	7.38
2000	7.70	28.57	14.86	63	0.69	6.95
2000	5.10	28.13	14.70	66	0.70	6.72
2000	6.42	27.44	14.81	67	0.67	6.42
2000	3.20	27.73	14.69	66	0.73	6.66
2000	3.56	27.67	14.41	66	0.68	7.11
2000	3.97	27.78	14.67	66	0.66	6.94
2001	6.18	27.31	14.70	67	0.71	6.23
2001	5.73	27.31	14.90	66	0.73	7.41
2001	2.98	27.27	14.21	66	0.75	7.16
2001	2.73	27.21	14.84	67	0.77	6.99
2001	3.86	27.23	14.60	67	0.67	6.44
2001	1.47	27.83	14.45	66	0.68	7.41
2001	3.05	27.81	14.35	66	0.76	7.69
2001	4.84	27.54	14.29	66	0.73	7.60
2001	3.47	27.75	14.54	68	0.79	7.51
2001	3.36	27.05	14.86	69	0.75	6.84

2001	4.88	27.62	14.35	66	0.79	7.75
2001	3.81	27.63	14.19	67	0.80	7.56
2002	3.54	27.45	14.39	66	0.90	7.56
2002	3.17	27.23	14.53	68	0.78	7.32
2002	4.38	27.00	14.58	67	0.82	7.65
2002	4.23	27.15	14.28	67	0.82	7.42
2002	6.05	27.42	14.14	67	0.78	7.68
2002	3.38	27.20	14.51	68	0.80	7.28
2002	4.78	27.14	14.13	66	0.80	7.36
2002	3.52	27.12	13.64	66	0.82	7.75
2002	3.25	26.68	14.21	68	0.88	6.95
2002	2.77	26.85	13.69	68	0.85	7.31
2002	4.17	26.90	14.18	67	0.90	7.83
2002	2.45	26.43	14.13	67	0.91	6.96
2003	3.30	26.54	14.78	67	0.87	6.87
2003	1.64	26.56	14.16	66	0.88	7.51
2003	3.41	26.56	14.37	66	0.87	6.85
2003	1.77	26.64	14.04	67	0.92	7.48
2003	2.61	26.34	14.27	67	0.92	7.15
2003	2.12	26.86	14.77	66	1.01	7.15
2003	4.26	26.64	15.01	66	1.03	7.94

2003	3.55	26.51	14.72	68	0.92	6.75
2003	3.63	26.10	14.32	69	0.93	6.90
2003	3.24	26.30	14.40	67	0.97	7.14
2003	2.51	26.68	14.51	67	0.96	7.37
2003	3.94	26.32	14.49	68	0.99	6.86
2004	1.71	25.83	15.32	67	1.02	5.85
2004	3.43	26.23	14.50	67	0.98	6.75
2004	2.52	25.78	14.77	69	0.97	6.44
2004	3.74	25.87	14.45	68	1.02	6.54
2004	3.18	25.59	14.54	68	1.02	6.66
2004	3.83	25.67	14.78	68	1.01	5.82
2004	2.66	25.51	14.78	69	0.94	5.84
2004	2.14	25.40	14.69	67	0.99	6.34
2004	3.62	25.55	14.44	67	1.10	6.35
2004	2.64	25.67	14.28	67	0.94	6.55
2004	5.27	25.17	14.62	66	1.03	5.70
2004	4.30	25.32	14.54	67	0.89	5.78
2005	2.99	25.39	14.59	68	0.88	6.04
2005	4.01	25.15	14.55	69	0.97	5.05
2005	2.91	25.23	14.62	68	0.99	5.37
2005	3.25	25.10	14.70	68	0.97	5.50

2005	3.73	25.08	14.88	69	0.84	5.02
2005	1.66	24.77	13.61	68	1.03	5.25
2005	2.05	25.65	14.17	68	0.90	5.89
2005	3.48	25.10	14.86	70	0.93	4.60
2005	3.19	25.38	14.36	69	0.90	5.80
2005	2.71	24.91	14.50	69	0.94	5.80
2005	2.14	24.77	14.44	69	0.91	5.18
2005	6.68	24.83	14.76	70	0.90	4.94
2006	1.90	24.74	14.64	72	0.85	4.36
2006	2.28	24.83	14.45	70	0.88	5.78
2006	3.78	24.51	14.63	71	0.79	4.02
2006	2.32	24.79	14.36	69	0.92	5.15
2006	2.53	24.56	14.92	70	0.87	4.62
2006	2.52	24.71	14.72	70	0.76	4.87
2006	2.36	24.99	14.76	71	0.78	4.81
2006	2.06	24.91	14.70	70	0.86	4.55
2006	4.78	24.83	15.16	69	0.81	4.58
2006	5.18	24.99	14.65	70	0.84	5.03
2006	4.57	24.99	14.35	69	0.91	5.22
2006	4.86	24.57	14.49	70	0.83	4.28
2007	5.66	24.69	14.51	68	0.87	5.00

2007	7.24	24.66	14.64	71	0.90	4.43
2007	5.37	24.44	14.68	73	0.83	4.46
2007	6.87	24.37	14.38	73	0.82	4.76
2007	4.49	24.56	14.82	71	0.81	4.48
2007	3.65	24.28	14.71	72	0.87	4.00
2007	4.55	24.06	13.98	71	0.82	3.87
2007	3.03	24.54	14.30	71	0.86	5.18
2007	2.15	24.58	14.61	72	0.76	4.69
2007	5.97	24.38	14.57	71	0.92	4.28
2007	8.76	24.27	14.93	73	0.83	3.67
2007	7.94	24.73	14.57	71	0.74	4.80
2008	2.74	24.51	14.57	71	0.86	4.19
2008	5.01	24.19	14.80	70	0.89	4.68
2008	4.20	24.54	14.30	69	0.82	4.69
2008	3.94	24.77	14.69	68	0.84	5.37
2008	3.83	24.61	14.43	70	0.86	5.27
2008	3.75	24.80	14.66	69	0.77	5.07
2008	3.99	25.26	14.93	68	0.87	5.56
2008	6.04	24.67	15.02	73	0.75	4.58
2008	2.20	24.37	14.83	71	0.80	4.22
2008	2.89	24.47	14.59	71	0.84	4.61

2008	5.48	24.78	14.63	73	0.75	4.57
2008	6.81	24.78	15.18	71	0.76	4.65
2009	4.55	24.73	14.80	70	0.78	4.87
2009	3.49	24.61	14.50	70	0.81	5.21
2009	3.72	25.23	14.27	68	0.84	5.59
2009	5.67	25.11	14.58	70	0.86	5.44
2009	5.01	25.09	14.39	71	0.80	5.96
2009	7.39	24.95	14.38	70	0.76	5.63
2009	3.64	25.29	14.29	71	0.71	5.34
2009	3.83	25.58	13.87	68	0.84	7.16
2009	5.85	25.67	14.43	68	0.74	6.62
2009	4.12	25.33	14.75	71	0.76	5.68
2009	9.21	25.45	14.49	70	0.73	5.67
2009	8.75	25.26	14.62	71	0.71	5.71
2010	2.56	25.64	14.40	70	0.73	6.61
2010	4.55	25.13	14.54	71	0.71	5.06
2010	3.65	24.68	14.24	71	0.81	5.09
2010	4.45	25.32	14.23	68	0.75	5.73
2010	4.92	25.61	14.33	69	0.80	6.06
2010	6.93	24.95	14.26	71	0.75	5.42
2010	5.98	25.16	14.51	69	0.82	5.49

2010	3.83	25.39	14.65	69	0.70	5.46
2010	5.31	25.78	14.26	70	0.74	5.85
2010	5.03	25.47	14.10	72	0.76	5.30
2010	5.02	25.44	14.24	70	0.71	5.72
2010	3.83	25.79	13.99	69	0.75	6.10
2011	3.81	25.84	14.60	71	0.74	6.06
2011	5.79	25.74	14.08	70	0.71	6.04
2011	6.40	25.85	13.90	69	0.69	5.88
2011	5.89	25.62	14.21	73	0.71	5.90
2011	4.00	25.44	13.42	70	0.65	5.78
2011	3.19	25.57	13.37	69	0.63	6.60
2011	3.21	25.75	13.51	68	0.65	5.86
2011	4.33	25.57	13.70	70	0.62	5.67
2011	3.67	25.44	13.91	69	0.60	5.87
2011	3.17	25.63	14.19	71	0.58	5.53
2011	3.80	25.91	13.86	69	0.65	5.82
2011	3.23	25.96	13.73	69	0.62	5.86
2012	5.07	26.03	14.03	68	0.59	6.19
2012	5.25	25.69	14.15	72	0.62	5.59
2012	4.48	26.12	13.93	71	0.68	6.12
2012	4.75	26.10	14.26	71	0.62	5.73

2012	8.05	25.71	13.97	73	0.62	5.09
2012	3.69	26.06	13.55	69	0.60	6.04
2012	4.01	25.93	13.86	70	0.62	6.23
2012	5.70	25.42	14.27	72	0.53	5.24
2012	5.52	25.65	14.20	72	0.54	5.02
2012	5.07	26.19	14.19	69	0.62	6.15
2012	4.52	25.91	14.07	71	0.55	5.81
2012	4.69	26.15	14.17	70	0.56	6.02
2013	3.23	26.19	14.01	69	0.59	6.06
2013	4.32	26.23	14.17	69	0.59	5.78
2013	3.13	25.29	13.31	69	0.64	4.98
2013	3.55	25.88	14.15	68	0.54	5.85
2013	3.05	26.35	13.21	68	0.53	6.40
2013	5.85	26.64	13.40	66	0.51	6.89
2013	4.25	26.90	13.10	65	0.51	6.94
2013	3.32	26.87	13.89	66	0.53	6.61
2013	3.83	26.63	13.51	67	0.53	6.62
2013	6.19	26.44	14.03	69	0.55	6.28
2013	2.96	26.44	13.59	69	0.49	6.27
2013	3.32	26.37	13.84	67	0.54	5.92
2014	3.61	26.39	14.07	67	0.54	5.37

2014	4.03	26.89	14.08	66	0.53	5.64
2014	2.68	26.90	13.41	62	0.53	6.52
2014	2.42	27.51	13.05	62	0.58	7.64
2014	2.31	27.13	13.21	63	0.55	7.44
2014	1.23	27.15	12.87	63	0.56	7.26
2014	1.80	27.43	12.29	60	0.57	7.50
2014	3.54	27.26	12.85	61	0.55	7.52
2014	4.51	27.22	12.77	62	0.54	6.78
2014	4.44	27.15	13.30	62	0.61	6.59
2014	3.02	26.91	12.97	61	0.50	7.15
2014	1.50	27.28	12.58	57	0.56	8.19
2015	1.00	27.54	12.17	61	0.55	7.76
2015	1.44	27.65	12.67	58	0.55	7.78
2015	1.85	27.45	12.47	59	0.55	7.45
2015	2.70	27.91	12.19	57	0.53	8.37
2015	2.46	27.73	11.65	57	0.53	8.53
2015	1.46	27.84	11.61	56	0.53	8.33
2015	3.25	27.57	12.21	56	0.54	7.80
2015	1.62	27.75	12.30	58	0.52	7.98
2015	1.38	27.79	11.86	56	0.57	8.36
2015	0.96	28.14	10.99	53	0.55	9.08

2015	1.11	28.59	10.61	52	0.59	9.49
2015	1.16	28.39	10.82	54	0.60	9.53
2016	1.65	28.27	11.72	55	0.59	8.70
2016	1.21	28.02	11.37	53	0.61	8.22
2016	1.24	27.86	11.34	55	0.64	8.35
2016	0.79	28.37	11.76	53	0.62	9.02
2016	1.36	28.24	11.39	54	0.63	8.79
2016	2.18	27.99	11.38	56	0.57	8.15
2016	1.40	28.12	11.51	53	0.61	8.68
2016	4.76	27.88	11.44	54	0.61	8.49
2016	1.47	28.12	11.20	53	0.59	9.03
2016	0.84	28.34	10.96	52	0.60	9.05
2016	0.72	28.40	10.87	52	0.64	8.42
2016	0.76	28.51	11.05	53	0.64	8.99
2017	1.05	28.18	11.43	53	0.68	8.40
2017	0.73	28.54	10.92	51	0.65	9.22
2017	1.31	28.56	11.19	52	0.66	9.05
2017	0.46	28.55	11.03	51	0.59	9.18
2017	0.83	28.10	10.67	53	0.62	8.95
2017	0.29	28.17	11.03	52	0.65	8.97
2017	1.24	27.99	10.95	53	0.64	8.84

2017	0.91	28.38	11.31	51	0.61	8.33
2017	1.35	28.39	11.03	53	0.60	8.63
2017	2.39	27.95	10.99	55	0.57	8.32
2017	0.68	28.12	10.81	54	0.68	8.98
2017	2.77	27.83	11.50	55	0.65	8.44
2018	2.80	28.29	11.07	53	0.62	8.85
2018	0.97	27.91	10.85	53	0.66	9.03
2018	0.36	28.27	10.57	52	0.66	8.63
2018	0.31	28.10	10.72	52	0.68	8.79
2018	0.97	27.87	10.06	51	0.73	9.02
2018	0.13	27.97	11.64	52	0.62	8.45
2018	1.11	28.20	10.68	53	0.64	9.03
2018	1.19	27.96	10.53	52	0.65	8.75
2018	0.03	28.39	10.32	50	0.64	9.01
2018	0.94	28.24	10.56	52	0.65	9.41
2018	0.94	28.28	10.88	51	0.68	9.30
2018	0.94	27.78	10.37	53	0.66	9.10
2019	0.21	28.01	10.19	54	0.72	9.26
2019	0.63	28.46	10.98	54	0.67	9.36
2019	0.59	28.36	10.80	54	0.71	8.79
2019	0.71	27.81	11.43	54	0.67	8.66

2019	0.66	28.09	10.59	51	0.69	8.81
2019	0.72	28.18	9.85	49	0.62	9.20
2019	0.35	28.27	9.22	49	0.62	9.29
2019	0.62	28.53	10.02	49	0.62	9.79
2019	0.22	28.58	10.50	49	0.62	9.81
2019	0.05	28.79	10.99	48	0.70	9.46
2019	0.71	28.10	10.26	50	0.70	9.57
2019	0.12	28.19	10.39	50	0.72	9.72
2020	0.71	28.29	10.82	49	0.68	9.84
2020	0.07	27.94	10.52	51	0.70	9.20
2020	0.01	28.24	10.96	51	0.89	9.08
2020	1.01	28.28	11.06	51	0.68	9.10
2020	0.53	28.49	10.97	52	0.71	9.08
2020	0.32	28.40	11.19	50	0.71	9.28
2020	1.26	28.48	10.50	50	0.72	9.15
2020	0.96	28.34	10.19	51	0.73	9.38
2020	0.77	28.14	11.03	51	0.79	9.10
2020	0.54	28.33	11.67	51	0.78	9.44
2020	0.24	28.42	11.31	50	0.71	9.45
2020	0.11	28.69	10.20	50	0.64	9.04

Appendices 1. 2 photos taken during soil sample taking for soil physical properties analysis

Appendices 1. 3 Soil laboratory analysis result at S/N/N/P/E Design and Supervision works, and Hawassa university IoT campus

Soil Testing Laboratory Color Determination

No.	Sample code	Profile depth	Observed results	Cooler
1	A	0-20	GLEY1 8/10Y	Light greenish gray
2	B	20-40	5YR 8/2	Pinkish white
3	C1	40-48	5Y 7/1	white
4	C2	48-60	5Y 5/1	gray
5	D	60-80	2.5Y 5/1	gray
6	E1	80-89	10YR 7/1	Dark reddish gray
7	E2	89-100	5Y 3/1	Very dark gray

Site: Wondo Genet Edo Kebele

0-20 cm: horizon 1

20-40 cm: horizon 2

40-48 cm: horizon 3

48-60 cm: horizon 4

60-80 cm: horizon 5

80-89 cm: horizon 6

89-100 cm: horizon 7

No	Soil profile	%FC	%PW	Texture			
				%Sand	%Clay	%Silt	Class
1	Horizon B	27.71	9.63	50	6	44	Loam
2	Horizon A(B12)	34.89	23.06	32	10	58	Silt Loam
3	Horizon C1	28.24	19.99	70	6	24	Sandy Loam
4	Horizon E2	35.57	14.10	32	4	64	Silt Loam
5	Horizon E1	35.57	16.63	60	6	34	Sandy Loam
6	Horizon C2	36.98	18.91	54	0	46	Sandy Loam
7	Horizon D	23.41	13.70	56	0	44	Sandy Loam

Soil Testing Laboratory

Appendices 1. 4 Particle size Determination and bulk density

Profile depth (cm)	Textural class	Per cent sand	per cent silt	per cent clay	bulk density (gram/cm3)	Particl esize(mm)
0-20	silt loam	32	58	10	0.821	4µm
20-40	loam	50	44	6	0.973	0.2
40-48	sandy loam	70	24	6	0.733	0.3

48-60	sandy loam	54	46	0	0.867	0.3
60-80	sandy loam	56	44	0	0.939	0.3
80-89	sandy loam	60	34	6	0.818	0.3
89-100	silt loam	32	64	4	1.007	4µm

Appendices 1. 5 Calibrated soil hydraulic parameter

soil layer	Depth in(cm)	Sand	Silt	Clay	Qr(cm^3/cm^3)	Qs(cm^3/cm^3)	α (cm-1)	n	ks(cm/day)
1	0-20	32	58	10	0.0481	0.41887	0.0047	1.675	40.45
2	20-40	50	44	6	0.0346	0.4029	0.0125	1.487	42.64
3	40-48	70	24	6	0.035	0.3897	0.038	1.445	58.47
4	48-60	54	46	0	0.024	0.4314	0.0182	1.462	92.5
5	60-80	56	44	0	0.0239	0.4282	0.0212	1.446	89.52
6	80-89	60	34	6	0.0336	0.394	0.025	1.416	51.19
7	89-100	32	64	4	0.0372	0.4471	0.005	1.698	83.4

Appendices 1. 6 The van Genuchten soil hydraulic parameters, obtained from calibration of Hydru-1D model (Rosetta model)

Textural class	Qr(cm3/cm3)	Qs(cm3/cm3)	α (cm-1)	n	ks(cm/day)	I
silt loam	0.0641	0.5312	0.0037	1.7462	40.45	0.5
loam	0.0426	0.4548	0.0079	1.5436	42.64	0.5
sandy loam	0.0478	0.5918	0.0257	1.3609	58.47	0.5
sandy loam	0.0357	0.4811	0.0095	1.4934	92.5	0.5
sandy loam	0.0336	0.4605	0.0118	1.4673	89.52	0.5

sandy loam	0.0456	0.5341	0.0133	1.4352	51.19	0.5
silt loam	0.0475	0.4531	0.0039	1.7397	83.4	0.5

Appendices 1. 7 Appendices Specific Yield Values of the Geological Formations

S.N.	Formation	Recommended Value	Minimum Value	Maximum Value
(%)	(%)	(%)		
(a)	Alluvial areas			
Sandy alluvium	16	12	20	
Silty alluvium	10	8	12	
Clayey alluvium	6	4	8	
(b)	Hard rock areas			
Weathered granite, gneiss, and schist with low clay content	3	2	4	
Weathered granite, gneiss, and schist with significant clay content	1.5	1	2	
Weathered or vesicular, jointed basalt	2	1	3	
Laterite	2.5	2	3	
Sandstone	3	1	5	
Quartzite	1.5	1	2	
Limestone	2	1	3	
Karstified limestone	8	5	15	
Phyllites, Shales	1.5	1	2	
Massive poorly fractured rock	0.3	0.2	0.5	

Appendices 1. 8 Location of water level monitoring wells in the Wondo Genet Edo watershed and average water depth 2021-2022 (The point 266-313 are an area of the conserved land, 314-317 is sample point and 318-342 is the point of monitoring well)

IDENT	LAT	LONG	Y_PROJ	X_PROJ	ALTITUDE	DEPTH	MODEL
266	6.992824	38.58298	772768.6	453843.5	1774	0	GPS 72H
267	6.992813	38.58296	772767.4	453841.4	1777	0	GPS 72H
268	6.99293	38.58301	772780.4	453846.2	1780	0	GPS 72H
269	6.993037	38.5831	772792.1	453857	1780	0	GPS 72H
270	6.993091	38.58327	772798.1	453875.5	1781	0	GPS 72H
271	6.993074	38.58338	772796.2	453887.2	1782	0	GPS 72H
272	6.993331	38.5835	772824.6	453901.3	1784	0	GPS 72H
273	6.993332	38.5835	772824.7	453901.2	1784	0	GPS 72H
274	6.993332	38.5835	772824.7	453901.2	1784	0	GPS 72H
275	6.993332	38.5835	772824.7	453901.2	1783	0	GPS 72H
276	6.993332	38.5835	772824.7	453901.2	1784	0	GPS 72H
277	6.993332	38.5835	772824.7	453901.2	1784	0	GPS 72H
278	6.993331	38.5835	772824.6	453901.2	1784	0	GPS 72H
279	6.993331	38.5835	772824.7	453901.2	1784	0	GPS 72H
280	6.993307	38.5835	772822	453900.8	1783	0	GPS 72H
281	6.993311	38.58352	772822.4	453902.6	1783	0	GPS 72H
282	6.993482	38.58346	772841.3	453896.1	1783	0	GPS 72H
283	6.993557	38.58348	772849.6	453898.1	1783	0	GPS 72H
284	6.993492	38.58363	772842.4	453915.7	1785	0	GPS 72H
285	6.993568	38.58384	772850.8	453938.1	1788	0	GPS 72H
286	6.993597	38.58396	772854	453951.5	1791	0	GPS 72H
287	6.993675	38.5841	772862.6	453967.5	1793	0	GPS 72H
288	6.993845	38.58423	772881.4	453981.2	1794	0	GPS 72H
289	6.993907	38.58442	772888.2	454002.3	1796	0	GPS 72H
290	6.993855	38.5846	772882.4	454022.7	1798	0	GPS 72H
291	6.993932	38.58477	772891	454040.6	1802	0	GPS 72H

292	6.993864	38.58495	772883.4	454061.4	1808	0	GPS 72H
293	6.993152	38.58505	772804.7	454071.7	1815	0	GPS 72H
294	6.99288	38.58505	772774.6	454072.2	1814	0	GPS 72H
295	6.992549	38.58509	772738	454076.7	1811	0	GPS 72H
296	6.992199	38.58509	772699.4	454076.5	1811	0	GPS 72H
297	6.991853	38.58505	772661	454072.3	1809	0	GPS 72H
298	6.991837	38.585	772659.3	454066.3	1808	0	GPS 72H
299	6.991669	38.58494	772640.7	454059.3	1804	0	GPS 72H
300	6.991656	38.58466	772639.4	454028.9	1798	0	GPS 72H
301	6.991764	38.58436	772651.3	453995.9	1794	0	GPS 72H
302	6.991867	38.58418	772662.7	453975.3	1793	0	GPS 72H
303	6.992018	38.58394	772679.4	453949.5	1791	0	GPS 72H
304	6.992085	38.58383	772686.8	453936.8	1788	0	GPS 72H
305	6.992206	38.58366	772700.2	453918.9	1787	0	GPS 72H
306	6.992354	38.58347	772716.6	453897.4	1784	0	GPS 72H
307	6.992483	38.58331	772730.9	453879.4	1781	0	GPS 72H
308	6.992601	38.58309	772744	453855.7	1779	0	GPS 72H
309	6.992731	38.5829	772758.4	453834.3	1775	0	GPS 72H
310	6.99276	38.58284	772761.6	453827.8	1775	0	GPS 72H
311	6.992773	38.58286	772763	453829.6	1774	0	GPS 72H
312	6.992788	38.5829	772764.6	453835	1775	0	GPS 72H
313	6.992788	38.5829	772764.7	453835	1775	0	GPS 72H
314	6.992197	38.58423	772699.1	453981.4	1790	0	GPS 72H
315	6.992191	38.58422	772698.5	453979.7	1790	0	GPS 72H
316	6.992179	38.58422	772697.2	453980.4	1790	0	GPS 72H
317	6.99219	38.58424	772698.4	453982.3	1790		GPS 72H
318	6.987046	38.57934	772130.2	453440.9	1721	12	GPS 72H
319	6.98723	38.57916	772150.6	453421.3	1718	10	GPS 72H
320	6.98704	38.5788	772129.6	453380.5	1727	12	GPS 72H
321	6.98672	38.57875	772094.3	453375.9	1721	10	GPS 72H

322	6.986236	38.57792	772040.8	453283.4	1720	6	GPS 72H
323	6.986302	38.57763	772048.2	453251.9	1718	6	GPS 72H
324	6.986235	38.57732	772040.8	453217	1717	8	GPS 72H
325	6.984511	38.57777	771850.1	453267.1	1701	37	GPS 72H
326	6.984721	38.58003	771873.1	453517	1729	27	GPS 72H
327	6.986475	38.57621	772067.4	453094.7	1712	12	GPS 72H
328	6.987222	38.57572	772150.1	453041.1	1727	8	GPS 72H
329	6.987735	38.57544	772206.8	453010.4	1720	9	GPS 72H
330	6.988013	38.57546	772237.5	453012.4	1717	13	GPS 72H
331	6.987859	38.57537	772220.5	453001.9	1718	12	GPS 72H
332	6.98945	38.57592	772396.3	453063	1702	8	GPS 72H
333	6.989744	38.57606	772428.8	453078.4	1706	10	GPS 72H
334	6.989815	38.57629	772436.6	453104.4	1706	8	GPS 72H
335	6.989897	38.57692	772445.6	453173.9	1706	7	GPS 72H
336	6.990748	38.57751	772539.7	453238.9	1704	9	GPS 72H
337	6.991589	38.57853	772632.6	453351.5	1708	8	GPS 72H
338	6.991373	38.57827	772608.7	453323.3	1714	7	GPS 72H
339	6.990424	38.57878	772503.7	453378.9	1712	8	GPS 72H
340	6.989185	38.57756	772366.9	453243.9	1709	5	GPS 72H
341	6.989195	38.57825	772367.9	453320.2	1713	5	GPS 72H
342	6.989674	38.5794	772420.7	453447.1	1714	8	GPS 72H

Appendices 1. 9 Wondo Genet, Edo-watershed assess land management practices on groundwater recharge Questionnaires

Questionnaires were developed to gather data from farmers and hand-dug good users /owners for partial fulfillment of the Degree of Master of Science in Water Resource Engineering and Management. It has objectives, for the assessment of land management practices on groundwater recharge in Wondo Genet woreda, Edo watershed.

Questions were structured to collect information that was immediately available or easily obtained by the farmers and well owner. Information on land management practices and well user/owner was collected to allow for assessing the impact of land management practices on groundwater recharge in the study site.

A: Contact Information and location

Respondent

Name ________________________________

Do agree to answer this question? A) yes B) no if you are is yes, go next step

Sex ________________________________

Number of household______________________

Village ____________________________

Phone number_________________________________

1. Do you have your own land?

1. Yes 2. No

2. If yes, the size in hectares

2.1. Farm land----------------------------

2.2. Grazing land-------------------------

2.3. Homestead---------------------------

3. What is the nature of land form is in your area?

1. Flat land

2. Gentle slope

3. Moderately sloping

4. Steep slope

4. Which kinds of agricultural practice and input you use on your farm plot to sustainable manage the land resources?

1. Fertilizer (organic or chemical)

2. Improved seeds

3. Pesticides and insecticides

4. Irrigation, water

5. Do you participate on land management practices in your area?

1. Yes 2. No

6. If answer for question 12 is yes, which SWC measure you use?(More than one answer is possible)

1. Crop rotation

2. Adding plant residue

3. Drainage ditches.

4. Strip cultivation

5. Fallowing

6. Contour farming

7. Stone/ Soil Bund

8. Check the dam

9. Cut off the drain

7. What are the determinant factors of land management practices in your area?

1. Topography

2. Vegetation

3. Purpose of land use

4. Lack of awareness

8. Do you know about the practices of land management in your area?

1. Yes 2.no

9. What is the crucial problem of land management practices in your area?

1. Lack of awareness

2. Shortage of arable land

3. Improved technology

4. Unemployment

10. Do have access of agricultural extension services that enable to bring sustainable land management in your area?

1. Yes 2. No

11. What you think about the solution of problem in current and future in your area?____

____

12. Which one is the dominant practice of land management in your area?
1. Terracing 2. Farming system

13. Are there any other modern practices of land management in your area?
1. Yes 2. No

14. Generally what is your opinion on land management practices? And do you have a suggestion for sustainable land management in your area?

____

____

____

____

15. What facilities and supports that you need from the government and other bodies to manage your farmland?

____

____

B: Water use

1. What is the most important water source for your hh?
   1=Shallow well, 2=Bore hole, 3=Tap Water, 4=Nearby River, 5=Lake, 6=Reservoir, 7=other

2. Do you use well water? A) No B) Yes, but for only home C) Yes, but for only farm

3. How many wells do you have?

4. How deep is your farm well(s)? *(*m*)* ‰ *Don't Know*

5. How much meter square of land do you have?

Appendices 1. 10 Questionnaires for Key Informant Interview

1. What is land management?

2. What are modern land management practices implemented in your area?

3. What are the criteria that you use to select land management practice?

4. What do you think about the benefit obtained from land management?

5. What are the main constraints and opportunities regarding land management practices

6. How did you evaluate trends of land management carried out in the past and present?

7. What do you think is the challenge for effective land management practice and also what are the best remedies?

8. What are the best practices of land management currently?

9. What measures do you suggest for current and future practices of land management to be sustained?

Appendices 1. 11 Captured picture during fieldwork.