ESTIMATION OF SPATIALLY DISTRIBUTED GROUNDWATER RECHARGE AND ITS QUALITY EVALUATION FOR IRRIGATION, MODJO RIVER CATCHMENT, CENTRAL ETHIOPIA

MSc THESIS

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Estimation of Spatially Distributed Groundwater Recharge and Its Quality Evaluation for Irrigation, Modjo River Catchment, Central Ethiopia

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APPROVAL SHEET

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We hereby certify that we have read and evaluated this Thesis titled "**estimation of spatially distributed groundwater recharge and its quality evaluation for irrigation, Modjo river catchment, central Ethiopia**" prepared under our guidance by *Negash Bedaso Dalechca*. We recommend that it be submitted as fulfilling the thesis requirement.

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Final approval and acceptance of the thesis is contingent up on the submission of the final copy of the thesis to the Postgraduate Programs Directorate through the candidate's department or Haramaya Institute of Technology Graduate Committee (HIGC).

DEDICATION

This manuscript is dedicated to the memory of my sister **Halima Bedaso**; she passed away without seeing my victory

To my parents, my mother Qandi Mandjo, my father Bedaso Dalecha and my brother Hirpo Bedaso who instilled in me the inspiration to set high goals and the confidence to achieve them

STATEMENT OF THE AUTHOR

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

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BIOGRAPHICAL SKETCH

The author was born in Gadab Asasa Woreda, West Arsi Zone of Oromia Regional State, of Ethiopia in January 5, 1986. He began his education at Assela Lutheran mission elementary school and his secondary and high school at Chilalo high school. After finishing high school, he joined Haramaya university and graduated with Bachelor of Science Degree in soil and water Engineering and Management on September 15, 2011 and employed at Oromia Agricultural research institute Sinana Agricultural research center and served as assistant researcher from (2011-2015)GC. After serving for three years, he joined Haramaya University postgraduate program to pursue his Master of Science degree in Irrigation Engineering.

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ACRONYMS AND ABBREVIATIONS

AET	Actual evapotranspiration
DEM	Digital Elevation Model
DHB	Distributed Hydrological Budget
EC	Electrical Conductivity
ECiw	Electrical Conductivity of Irrigation Water
ET	Evapotranspiration
ETo	Reference evapotranspiration
ETM+	Enhanced Thematic Mapper Plus
FAO	Food and Agriculture organization of the United Nation
GIS	Geographic Information System
GPS	Global Positioning System
IWMI	International water resource management institute
JICA	Japanese International Cooperation Agency
MoWIE	Ministry of Water, Irrigation and Electricity
Mkm^3	Million cubic meter
NMA	National Metrological Agency
PET	Potential Evapotranspiration
PPM	Per parts million
SAR	Sodium Adsorption Ratio
SARIW	Sodium Adsorption Ratio of Irrigation Water
SNHT	Standard Normal Homogeneity Test
SRTM	Shuttle radar topographic mission
TDS	Total dissolved salt
UNFCCC	United Nations Framework Convention on Climate Change
UNESCO	United nations educational, scientific and cultural organization
USGS	United States Geological Survey
WAPCOS	Water and energy consultancy service
WetSpass	Water and Energy transfer between soil, plants and atmosphere under quasi-Steady state
WSP	Water and Sanitation Program

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ABSTRACT

Knowledge of groundwater resource potential is important for groundwater management and sustainable use. Recharge is an important factor in evaluating groundwater resources but difficult to quantify. Hence estimation of groundwater recharge requires modeling of the interaction between all the important processes in the hydrological cycle. In this study the long term seasonal and annual groundwater recharge of Modjo river catchment (2,202 km^2) was estimated and recharge map were developed through a grid based physically distributed model, WetSpass. Long term average hydro-meteorological data and spatial pattern of watershed physical grid maps were used as main inputs for the model. All input maps for the model were prepared using ArcGIS 10.2 spatial analysis tool. Soil, land use and runoff coefficient parameters in dbase files, season independent gridded base map of topography, slope, and soil were used in the model; whereas precipitation, potential evapotranspiration, temperature, wind speed, groundwater depth and land use map were prepared and employed by the model, in ASCII grid format for both winter and summer seasons. For irrigation water quality analysis, the groundwater samples were collected from well and borehole of different site and analyzed in lab for necessary parameters. From the result, it is found that the long-term temporal and spatial average annual rainfall of 933 mm was distributed as: surface runoff of 164 mm (17.6%), evapotranspiration of 686 mm (73.5%), and recharge of 83 mm (8.9%). Thus an average of 183Mm^3 of groundwater will be recharged per year or 5802 l/s from the catchment area. It has also seen that the water balance components are dependent on the soil type and land use classes, thus high values of groundwater recharge are observed in the grassland (31%) and agricultural land (29%) with silty loam and silty clay soils. This is due to relatively good permeability of these soils and gentle topography which favors more water infiltration contributing to recharge. Plotting of the chemical analysis of water samples collected in the area using piper graph shows that Na-Ca-HCO_3 water type in the recharge area, intermediate water type Ca-Mg-Na-HCO_3 in northern and central part of the subbasin and Ca-Mg-HCO_3 type towards the east and most of the water is clustered in the left part of the diagram, suggesting that the water in the study area is a Calcium-Sodium-Magnesium-Bicarbonate type, which is characterized by a high concentration of HCO_3 and Ca. Flood control dams (artificial recharge) practice was recommended in this study area to harvest the excess water (simulated annual surface runoff 361Mm^3) which is helpful in one way to reduce soil erosion and in the other way to enhance more recharge to groundwater. From water quality analysis; the concentrations in the water sample shows below the maximum allowable limits for irrigation (i.e.EC<2000 µS/cm and SAR<9*) and therefore the groundwater could be used safely for irrigation.*

Key words: Modjo subbasin, WetSpass, groundwater recharge, hydrochemistry, water quality

1. INTRODUCTION

Parallel to population growth, food and water demand of people are also increasing. Agricultural yield and productivity should be increased to provide a sustainable development and food security of the increasing population. In many areas of the world where extensive irrigation is not possible or impractical, the lack of sufficient water in the root zone of the soil can cause great societal disruption, especially to agricultural practice. Although the total water resources in the world are estimated to be1.36 Billion Km^3 (Raghunath, 2006), its spatial and temporal distribution remains uneven. Higher rate of population growth, enhanced living standards, extreme water pollution and the global climate change have made water endangered these days. In the same way rainfall in Ethiopia is varying highly and erratic in time and space (Yazew,2005),which lead to yield reduction due to water stress (Raghunath, 2006).

Groundwater is one of the most valuable natural resources, which supports in overcoming a rainfall shortage for crop production. It has become an important and dependable source of water supplies in all climatic regions including both urban and rural areas of developed and developing countries (Todd, 2005). Comprehensive statistics on groundwater abstraction and use are not available, but it is estimated that more than 1.5 billion people worldwide rely on groundwater for potable water (Clarke *et al.*, 1996). Other than water stored in icecaps and glaciers, groundwater accounts for approximately 97% of fresh water on Earth (Shiklomanov and Rodda, 2003).

Studies show erroneous results of 2.5 BCM by WAPCOS, to 185 BCM by Ayenew and Alemayehu, (2001, as cited in Moges, 2012) on groundwater potential of Ethiopia. Best guesses in this respect ranges between 12-30 BCM or even more if all aquifers in the lowlands are assessed (MoWIE, 2011). This ambiguity can be taken as an indication of how much detailed study and survey is needed to estimate the countries resources with a better precision; because such uncertainty can have a hindering effect on the countries pursuit to utilize its water resources potential to the limit. Knowledge of groundwater resource potential is important for its management and sustainable use, because the optimal exploitation of the groundwater requires a previous knowledge on the aquifers potential (Benjamin *et al.*, 2007).

Groundwater potential is directly dependent on recharge. For efficient and sustainable management of the groundwater resource, understanding and quantification of groundwater recharge have paramount importance (Obuobie *et al*., 2008). Recharge can be defined as the entry into the saturated zone of water made available at the water table surface. It is the process by which water percolates down the soil and reaches the water table either by natural or artificial methods to replenish the aquifer with water from the land surface. Groundwater recharge is a sensitive function of the climatic factors, local geological formation, topography and land use types of the area under consideration (Dragoni and Sukhija, 2013). The regime has a direct relationship with precipitation and physicochemical properties of soil. Thus, recharge is not static but dynamic which varies in space and time. As aquifers are depleted, recharge estimates have become more essential in determining appropriate levels of groundwater withdrawal (Vries and Simmers, 2002). In arid and semiarid areas, its assessment is a key challenge in determining sustainable yield of aquifers (Yongxin and Beekman, 2003; Crosbie *et al*., 2010).

Recharge is an important factor in evaluating groundwater resources but is difficult to quantify (Alley *et al*., 2002). Therefore groundwater models have been used as interpretation tools for investigating groundwater system dynamics,(Anderson andWoessner,1992). Hence, WetSpass was built as a physically based methodology for estimation of the long-term average, spatially varying, water balance components: surface runoff, actual evapotranspiration and groundwater recharge (Batelaan and Smedt, 2001 and 2007). It is an acronym for water and energy transfer between soil, plants and atmosphere under quasi-steady state that was built upon the foundations of the time dependent spatially distributed water balance model (Batelaan and Smedt, 2001 and 2007). In this study geographical information system GIS and WetSpass (Batelaan and Smedt, 2007) model, were used for groundwater recharge estimation.

Problems such as declines of groundwater heads and deterioration of groundwater quality have been observed in many places in last decades. In Ethiopia groundwater quality varies widely. It is primarily influenced by geology, physicochemical factors, biological factors, anthropogenic influences such as pollution from industrial, municipal and agricultural sources, geomorphologic and geographical setting as well as climatic condition (IWMI, 2012). And hence this study also includes analysis of important irrigation water quality parameter.

To formulate technically-sound groundwater resources management policies, decision makers always ask questions like: How long can an aquifer maintain the current rate of groundwater abstraction? What is the safety yield that the aquifer can sustain the continuous abstraction? What is the capture zone of a water supply well field? What is the most likely pathway of contaminants from domestic wastewater and leaches from solid waste disposal sites? What are the chances that the pollutants from those sources would arrive at water supply wells?

The analysis of estimating groundwater recharge and its quality examination for irrigation will assist scientific community, policy makers, donors, non-governmental organizations and other development practitioners to deliver right policy and programs in required areas on time. As a result, this study provides valuable data and baseline information in formulating technically sound groundwater resources management policies for the response of declining groundwater heads and deterioration of groundwater quality in the study area.

Consequently, this study was carried out with the general objective of estimating groundwater recharge and its quality evaluation for irrigation in the Modjo river catchment. Hence, the study was conducted with the following specific objectives:

- To develop groundwater recharge map in the catchment
- To estimate the average recharge within the catchment
- To determine the groundwater quality and examine its suitability for irrigation

2. LITERATURE REVIEW

2.1. Hydrologic Cycle

The hydrologic cycle is a constant movement of water above, on, and below the earth's surface. It is a cycle that replenishes groundwater supplies. Water is constantly cycled through the systems of land, soil, lakes, and groundwater, and river channels (UNESCO, 2001). The hydrological cycle also defined as a water transfer cycle occurs continuously in nature; at which the phenomena of evaporation and evapotranspiration, precipitation and runoff takes place during the water transfer system (Raghunath, 2006).

Water first evaporates from the surfaces of water bodies and transpires from surface vegetation as a vapor. Then the vapor rises up to the atmosphere, condenses and form clouds and then through process of condensation, results precipitation back to the earth surface. This precipitation flows as runoff to the oceans or infiltrates into the soil to be a groundwater. In hydrologic cycle, the water circulates in the lithosphere, hydrosphere, biosphere, cryosphere and atmosphere. As there is no loss or gain of water in the hydrologic cycle it can be considered as a closed system water circulation system for earth.

2.2. Precipitation and Evapotranspiration

Precipitation is the main driver of variability in the water balance over space and time, and changes in precipitation have very important implications for hydrology and water resources. Hydrological variability over time in a catchment is influenced by variations in precipitation over daily, seasonal, annual, and decadal time scales. Precipitation is taken as the starting point for the computation of the water balance of each of the components of a raster cell, the rest of the processes (interception, runoff, evapotranspiration, and recharge) follow in an orderly manner.

Evaporation from the land surface includes evaporation from open water, soil, shallow groundwater, and water stored on vegetation, along with transpiration through plants. The rate of evaporation from the land surface is driven essentially by meteorological controls, mediated by the characteristics of vegetation and soils, and constrained by the amount of water available. Evapotranspiration is important in soil water and ground water balances, which require estimating evapotranspiration to determine water storage, which, in turn, can lead to technical measures for the improvement of irrigation drainage and ultimately can be used to increase crop yield (Verstraeten *et al*., 2008).

2.3. Surface Water Resource

Seventy one percent of the Earth's surface is covered by water. Earth's surface water is held in two different kinds of water bodies: Salt water bodies and Fresh water bodies. The immediate use of water for human being is the one stored as groundwater and the remaining water found in land surfaces, lakes and streams as fresh water. Fresh water is defined as water that contains less than 0.5 ppt of dissolved salt (Nata, 2006) 99 % of the fresh water is locked up in snow and ice or in lakes, while rivers and other surface fresh water bodies make up 0.01 % of all the water in the world. When the surface water level is high enough, ground water comes to the surface naturally, like springs and may form lakes, ponds and rivers.

Ethiopia has abundant surface water resources that can be used for different purposes. There are 12 major river basins among which 7 of which are trans-boundary. The total annual runoff from these basins is estimated at about 111 billion cubic meter (MoWIE, 2001). The major rivers carry water and sediments and drain mainly to the arid regions of neighboring countries. There are also 11 major lakes with a total area of 750.000 ha (MoWIE, 2001).

2.4. Groundwater Resource

Groundwater is the water stored at underground/subsurface of the earth. It can also be defined as the water found below the surface of the land which exists in pores between sedimentary particles and in fissures and aquifers of solid rocks. The total groundwater of the world is estimated to be 10.53 Million km^3; and the groundwater comprises 99% of the earth’s available fresh water resources (Delleur, 1998). This part of water plays an important role in sustaining rivers, lakes and wetlands during dry periods and is also essential for many ecosystems. (Adem and Batelaan, 2006) Indicated that groundwater is a major source of water supply and food production on irrigated agricultures worldwide.

Many parts of Ethiopia have limited supplies of groundwater because of the poor permeability of the crystalline rocks and variable water-table depths, limited groundwater resources also relate strongly to low rainfall in eastern part of the country. As compared to surface water resources, the country has lower groundwater potential but the total exploitable groundwater potential is high as compared to other countries in Africa. Experience of exploiting groundwater in the country for irrigation is limited. As of 2004, the total groundwater irrigated areas in the country did not exceed two hundred hectares of horticulture and flower farms (Aytenffisu and Zemedagegnehu, 2004). Reviews of the different studies on groundwater conditions indicate there is high potential for developing groundwater sources for irrigation in specific areas. But knowledge available on groundwater resources of Ethiopia is very little. It needs to have a very detailed study on this issue so that enough information is available.

2.5. Groundwater Recharge

Groundwater recharge is the replenishment of an aquifer with water from the land surface. It is a movement of any water that enters into the groundwater system from any direction i.e. up, down or laterally (Russell, 2010). Groundwater recharge is usually expressed as an average rate of inches of water per year, similar to precipitation. In addition to precipitation, other sources of recharge to an aquifer are stream, lake or pond seepage, irrigation return flow (both from canals and fields), inter-aquifer flows, and urban recharge (from water mains, septic tanks, sewers, drainage ditches). When the sole source of such potential recharge is precipitation, it is usually called potential natural recharge. Potential natural recharge does not consider the other sources of recharge mentioned previously. The spatial variation in the recharge due to distributed land-use, soil type, and slope can be significant and should be accounted for these regional groundwater models. Stream flow recession analysis clearly shows this spatial variability of recharge (Chap man,1999). Factors that affects groundwater recharge include, rate and duration of precipitation, application of irrigation water, soil moisture content, geological formation, soil properties, depth of water table and aquifer properties, vegetation, land use, topography and land slope (Obuobie *et al*., 2008).

2.6. Groundwater Recharge Estimation

Quantifying the rate of recharge to aquifer is the most difficult of all measures in the evaluation of groundwater resources. Estimation of groundwater recharge requires modeling of the interaction between all the important processes in the hydrological cycle such as precipitation, infiltration, surface runoff, evapotranspiration, soil moisture and groundwater level variations (Jyrkama and Sykes, 2007). Recharge is estimated by chloride ion mass balance method, empirical method, water- balance method, water budget model method or by multiplying the magnitude of water-level fluctuations in wells with the specific yield of the aquifer material and hydrologic models are among those methods which are frequently used for groundwater estimation. Commonly groundwater recharge is determined to a large extent as an imbalance at the land surface between precipitation and evaporative demand (Gebreryfael, 2008). In general there are different models to estimate recharge in a given area depending on actual areal conditions. Ahmadi *et al*., (2013) used water balance principle (rainfall-groundwater level relationship) based approach to estimate groundwater recharge. These methods are WTF (Water Table Fluctuation), DHB (Distributed Hydrological Budget) and HB (Hydrological Budget). These methods were useful, easy to use, cost effective, simple, requiring few data such as groundwater level measurements, rainfall, aquifer properties and groundwater extraction datasets. Use of these methods helps to provide irrigation return flow percentage and contribution of precipitation to natural groundwater recharge.

2.6.1. Water balance approach recharge estimation

Water balance can be determined by calculating the input, output, and storage changes of water at the Earth's surface. The main input of water is from precipitation and output is from evapotranspiration. In water balance studies, it is usually assumed that the catchment is water tight and that no subsurface movement of water across the defined water shed is occurring. The evaluation of change in storage depends on the time period over which the water balance is being made on annual basis , the time at which the balance is effected is chosen so that the water stored in the ground and in surface storage is approximately the same each year and thus in the equation change in storage $\Delta S = 0$ (Shaw,1982) water balance equation representing the catchment: Water balance models were developed by Thornthwaite (1948) and revised by Thornthwaite and Mather (1955). The method is essential procedure, which estimates the balance between the inflow and outflow of water. Generally, water balance has the following form:

$$\text{Inflow} = \text{outflow} \pm \text{change in storage} \qquad (1)$$

This could be rewriting for the calculation of groundwater recharge as follow

Groundwater recharge = (precipitation + surface water inflow + imported water + Groundwater inflow) – (Evapotranspiration + reservoir evaporation + surface water out flow + exported water + Groundwater outflow + withdrawal) ± Change in storage (Fetter, 2001).

The main purpose of this computation is to make a quantitative evaluation of the amount of water that percolates in to the ground to recharge the groundwater circulation occurring in the investigating area. Therefore, assumptions made to derive the water balance equation are summarized as follows:

a) Since the computation is made annually, net change of the soil moisture and groundwater storage is assumed to be zero.
b) The area is part of the regional groundwater flow system and groundwater is not in closed system. Therefore, groundwater inflow from adjacent basin or area is equal to groundwater outflow in the adjacent basin or area.

Hence the above equation can be rewritten as follows: $P = AET + Eo + RO + G\,\Delta$ which is the general water balance equation set for the catchment in annual bases Where, P is Precipitation, Eo is Open water evaporation, RO is runoff, and G Δ is groundwater recharge.

For a long term calculation on annual bases the equation became;

Infiltration (Recharge) = (Precipitation – Actual Evapotranspiration – surface runoff) (2)

2.6.2. Base flow records recharge estimation

Extended periods of river base flow measurements can be used to estimate catchment area groundwater recharge (Ayenew, 1998). In estimating recharge for a given catchment from base flow the assumption is that the base flow of a river is equal to the total groundwater recharge of the catchment upstream of the discharge measuring site (Ayenew, 1998) in this case any loss upstream of the gauging station is considered to be negligible. In general there are different techniques for estimating groundwater recharge in regions with arid, semiarid, and humid climates as listed on the Table.1 below.

Table 1. Appropriate techniques for estimating groundwater recharge in regions with arid, semiarid and humid climates (Source; Scanlon *et al*., 2002).

Hydrologic zone	Groundwater recharge estimation techniques /methods	
	Arid and semiarid climate	Humid climate
Surface water	Channel water budget	Channel water budget
	Seepage meters	Seepage meters
	Heat tracers	Baseflow discharge
	isotopic tracers	isotopic tracers
	Subbasin modeling	Subbasin modeling
Unsaturated zone	Lysimetres	Lysimetres
	Zero-flux plane	Zero-flux plane
	Darcy's law	Darcy's law
	Tracers [historical (^{36}Cl,^{3}H),environmental (Cl)]	Tracers (applied)
	Numerical modeling	Numerical modeling
Saturated zone	_	Water-Table fluctuations
		Darcy's law
	Tracers [historical (CFCs, $^{3}H/^{3}He$),environmental (Cl,14C)]	Tracers [historical (CFCs, $^{3}H/^{3}He$)]
	Numerical modeling	Numerical

2.7. Hydrological Modeling

A scientific model is a testable idea, hypothesis, theory, or combination of theories that provide new insight or a new interpretation of an existing problem. Therefore, a model is not necessarily limited to mathematical formulations or always performed on a computer. In addition, models should be able to explain a large number of observations while maintaining simplicity, and are always a simplification of reality (Nordstrom, 2004).

With the increasing development of the groundwater resources and the growing impacts of human activities on the aquifers, problems such as declines of groundwater heads and deterioration of groundwater quality have been observed in many places in last decades. Approaches of sustainable development and integrated groundwater resources management must be developed and implemented to guarantee the right of use of the limited water resources for our future generations. To formulate technically-sound groundwater resources management policies, decision makers always ask questions like: How long can an aquifer maintain the current rate of groundwater abstraction? What is the safety yield that the aquifer can sustain the continuous abstraction? What is the capture zone of a water supply well field?

What is the most likely pathway of contaminants from domestic wastewater and leaches from solid waste disposal sites? What are the chances that the pollutants from those sources would arrive at water supply wells? How long it takes? In order to protect the well fields from pollution, a protection zone should be delineated. What is the size of the protection zone? (Yangxiao Zhou, 2017）

Providing answers to these questions involves the understanding of behavior of groundwater flow system and the prediction of the system's response to any stresses. The best tool available to help groundwater hydrologists to meet the challenges of the prediction is usually a groundwater model. Groundwater models have been used as:

1) Interpretation tools for investigating groundwater system dynamics and understanding the flow patterns;

2) Simulation tools for analyzing responses of the groundwater system to stresses;

3) Assessment tools for evaluating recharge, discharge and aquifer storage processes, and for quantifying sustainable yield;

4) Prediction tools for predicting future conditions or impacts of human activities;

5) Supporting tools for planning field data collection and designing practical solutions;

6) Screening tools for evaluating groundwater development scenarios;

7) Management tools for assessing alternative police;

8) Visualization tools for communicating key messages to public and decision-makers.

The conceptual model of the groundwater recharge process accounts for identifying the scale of the hydrological process, the inlets and outlets of the water circulation system as well as its temporal and spatial limitations, such as an area’s infiltration predisposition and the type or character of a hydro-logically active zone (Yair, Kossovsky, 2002, Dripps, Bradbury, 2007, Sorooshian, Hsu, 2008, Teklebirhan *et al*., 2012). Spatial variation in recharge due to distributed land-use, soil texture, topography, groundwater level, and hydro meteorological conditions are very important parameters which should be accounted in recharge estimation. Specifically, a geographical information system may provide the basic support for many distributed hydrological models.

Most of groundwater models used for analyzing groundwater systems (infiltration–discharge relations) are often quasi - steady state and, therefore, need long-term average recharge input.

Thus WetSpass, which yields spatially varying groundwater recharge using spatially varying meteorological, land use and soil inputs, can be used in conjunction with geographical information system for the purpose of understanding the characteristics of groundwater recharge.

2.7.1. WetSpass Model

WetSpass stands for water and energy transfer between soil, plants and atmosphere under quasi-Steady State (Batelaan and Smedt, 2001). It is a physically based model for the estimation of long-term average spatial patterns of groundwater recharge, surface runoff and evapotranspiration employing physical and empirical relationships. Regional groundwater models used for analyzing recharge-discharge relations are often quasi-steady and need long term average recharge input that accounts for the spatial variability of the recharge.

The research was done at Hasa basin (Al-zu'bi and Balqa,2010) aimed to estimate the water balance components including surface runoff, actual evapotranspiration and groundwater recharge by using WetSpass model. It was found that, the WetSpass model depends on the soil type and land use classes; hence lack of relevant land use map may lead to the wrong output which could lead to wrong decisions. However the model proven to provide good results provided that an accurate and up to date data are used. Another recent research was done by (Kuisi and El-Naqa, 2013) at Jafr basin in Jordan to estimate groundwater recharge by using GIS based spatial model; WetSpass. In this research both spatially and temporarily variation of recharge was taken into consideration. GIS and remote sensing were the key tools used on this research to accomplish modeling process by WetSpass model. Moreover, results obtained from the WetSpass model were compared with the estimated recharge to groundwater carried out by (JICA ,1990). The results demonstrated that the estimation of groundwater recharge using WetSpass is in good agreement with those obtained by other studies. Moreover WetSpass model was applied to analyzing the effects of topography, soil type, and land use cover on the runoff characteristics for upper Biebrza catchment (Szymczak, and Krężałek, 2010). The derivation of parameter maps and analysis of the daily runoff as reaction of the catchment on rainfall was performed. The values for the catchment justified the assessment of the model quality measurements as very good. The factors most affecting the process of river outflow formation were determined using the analysis of model sensitivity to relative changes in parameter values. It was found that the evaluation of the model quality depended largely on the quality of meteorological data and proper parameterization of the soil cover. From those remarkable records and user friendliness of the model, this model was used in this study.

WetSpass Input File

WetSpass requires ASCII grid files inputs, which are listed below:

Table 2.ASCII grid files for WetSpass input

ASCII Grid files	Tables (TBL)
Soil	
Topography	Soil parameter
Slope	Runoff coefficient
Groundwater depth* (summer and winter)	Land-use parameter
Land- use (summer and winter) or opt	
Temperature (summer and winter)	
Precipitation (summer and winter)	
PET* (summer and winter)	
Wind –speed (summer and winter)	

2.7.2. WetSpass application

The total water balance for a raster cell (Figure.1) is split into independent water balances for the vegetated, bare-soil, open-water and impervious parts of each cell. This allows one to account for the non-uniformity of the land-use per cell, which is dependent on the resolution of the raster cell. The processes in each part of a cell are set in a cascading way. This means that an order of occurrence of the processes, after the precipitation event, is assumed. Defining such an order is a prerequisite for the seasonal timescale with which the processes will be quantified. The quantity determined for each process is consequently limited by a number of constraints.

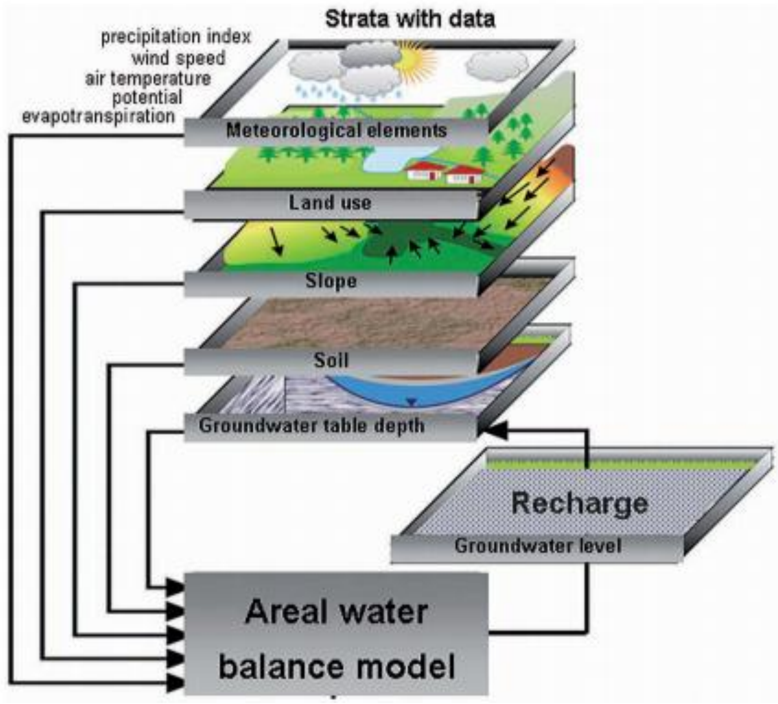


Figure 1. Schematization and integration of data for a hypothetical raster cell in the WetSpass water balance model, after Batelaan and Smedt (2001).

A. Water balance calculation

The water balance components of vegetated, bare-soil, open-water, and impervious surfaces are used to calculate the total water balance of a raster cell as follows:

$$ET_{raster} = avETv + asEs + aoEo + aiEi \quad (3)$$

$$S_{raster} = avSv + asSs + aoSo + aiSi \quad (4)$$

$$R_{raster} = avRv + asRs + aoRo + aiRi \quad (5)$$

where ET_{raster}, S_{raster}, R_{raster} are the total evapotranspiration, surface runoff, and groundwater recharge of a raster cell respectively, each having a vegetated, bare-soil, open-water and impervious area component denoted by av, as, ao, and ai, respectively.

Precipitation is taken as the starting point for the computation of the water balance of each of the above mentioned components of a raster cell, the rest of the processes (interception, runoff, evapotranspiration, and recharge) follow in an orderly manner.

B. Vegetated area

The water balance for a vegetated area depends on the average seasonal precipitation (P), interception fraction (I), surface runoff (Sv), actual transpiration (Tv), and groundwater recharge (Rv) all with the unit of [LT^{-1}], with the relation given below;

$$P=I+S_v+T_V+R_v \tag{6}$$

C. Surface runoff

Surface runoff is calculated in relation to precipitation amount, precipitation intensity, interception and soil infiltration capacity. Initially the potential surface runoff (Sv - pot) is calculated as;

$$S_v - pot = C_{sv}(P - I) \tag{7}$$

where, C_{sv} is a surface runoff coefficient for vegetated infiltration areas, and is a function of vegetation, soil type and slope. In the second step, actual surface runoff is calculated from the Sv-pot by considering the differences in precipitation intensities in relation to soil infiltration capacities.

$$S_v = C_{Hor}\, S_v - pot \tag{8}$$

where C_{Hor} is a coefficient for parameterizing that forms part of a seasonal precipitation contributing to the Hortonian overland flow. C_{Hor} for groundwater discharge areas is equal to 1.0 since all intensities of precipitation contribute to surface runoff. Only high intensity storms can generate surface runoff in infiltration areas.

D. Evapotranspiration

For the calculation of seasonal evapotranspiration, a reference value of transpiration is obtained from open-water evaporation and a vegetation coefficient;

$$Trv = cE_o \tag{9}$$

Trv = the reference transpiration of a vegetated surface [LT^{-1}];
Eo = potential evaporation of open water [LT^{-1}] and c= vegetation coefficient [–].

This vegetation coefficient can be calculated as the ratio of reference vegetation transpiration as given by the Penman Monteith equation to the potential open-water evaporation, as given by the Penman equation:

$$C = \frac{1+\frac{\gamma}{\Delta}}{1+\frac{\gamma}{\Delta}\left(1+\frac{r_c}{r_a}\right)} \qquad (10)$$

γ = psychrometric constant [$ML^{-1}T^{-2}C^{-1}$];

Δ = slope of the first derivative of the saturated vapor pressure curve (slope of saturation vapor pressure at the prevailing air temperature) [$ML^{-1}T^{-2}C^{-1}$];

rc = canopy resistance [TL^{-1}] and ra = aerodynamic resistance [TL^{-1}] given by;

$$r_a = \frac{1}{k^2 u_a}\left(ln\left(\frac{z_a-d}{z_0}\right)\right)^2 \qquad (11)$$

K is the Von Karman constant (0.4) [–]; u_a is the wind speed [LT^{-1}] at measurement level

z_a = 2m; d is the zero-plane displacement length [L] and z_o is the roughness length for the vegetation or soil [L]. For vegetated groundwater discharge areas, the actual transpiration (Tv) is equal to the reference transpiration as there is no soil or water availability limitation.

E. Recharge

The last component, the groundwater recharge, is then calculated as a residual term of the water balance, i.e,

$$Rv = P - Sv - ETv - Es - I \qquad (12)$$

ETv is the actual evapotranspiration [LT^{-1}] given as the sum of transpiration Tv and Es (the evaporation from bare soil found in between the vegetation). The spatially distributed recharge is therefore estimated from the vegetation type, soil type, slope, groundwater depth, and climatic variables of precipitation, potential evapotranspiration, temperature, and wind speed. WetSpass recharge outputs can be used as an input for the groundwater model like MODFLOW.

2.7.3. WetSpass adjustment to use it for the case of Ethiopia

WetSpass is originally developed for conditions in the temperate regions in general and Europe in particular. The land use and soils types and the number of weeks in a year that fall in the summer and winter seasons are all fixed based on the cases in Europe. However, the land use classes and the soils textural composition and classification for tropical countries like Ethiopia are apparently different than the case in temperate regions. Some land use classes, even if they literally exist in both climatic and tropical regions, are not the same in characteristics. For example, the forest in Ethiopia is not the same as what we can find in Belgium. Also for Belgium or temperate regions in general, the number of summer and winter seasons are six months each. In tropical regions like Ethiopia the number of months that fall in winter and summer seasons are eight (October to May) and four (June to September) respectively. In general winter is called as the dry season while summer is known as the main rainy season in Ethiopia. Therefore, modification of the model to adopt it for the cases in Ethiopia is compulsory before doing any watershed simulation with the model.

Likewise, in this particular study, the land use parameter table was modified and land use parameter tables for Ethiopian summer and winter seasons is developed, some of the seasonal land uses parameter values are readjusted as it has been used by (Tesfamichael *et al.*, 2010) in the Northern part of Ethiopia and used in the modeling processes.

2.8. Groundwater Quality for Irrigation

Irrigated agriculture is dependent on an adequate water supply of usable quality. Just as any water is not suitable for human beings, in the same way, any water is not suitable for plant life. Water containing impurities, which are injurious to plant growth, is not satisfactory for irrigation, and called unsatisfactory water. Water quality for agricultural purposes is determined on the basis of the effects of the water on the quality and yield of the crops, as well as the effects on drainage efficiency and characteristic changes in the soil (Wilcox, 1955).

Water quality concerns have often been neglected because good quality water supplies have been plentiful and readily available. This situation is now changing in many areas. Irrigation waters whether derived from springs, streams, or pumped from wells, contain appreciable quantities of chemical substances in solution that may reduce crop yield and deteriorate soil fertility. In addition to the dissolve salts, which has been the major problem for centuries, irrigation water always carry substances derived from its natural environment or from the waste products of man's activities (domestic and industrial effluents). These substances may vary in a wide range, but mainly consist of dirt and suspended solids (SS) resulting into the emitters' blockages in micro-irrigation systems, bacteria populations and coli-forms harmful to the humans and the animals (Pressurized irrigation techniques book cha-7.n.d). To avoid problems when using these poor quality water supplies, there must be sound planning to ensure that the quality of water available is put to the best use.

Water quality is defined by the physical, chemical and biological characteristics and composition of water sample. The chemical composition of groundwater is the combined result of water composition that enters the groundwater reservoir and the reactions with minerals present in the rocks (Iliopoulos *et al*., 2011).

The suitability of water for irrigation is determined by its potential to cause problems to soils and crops and related management practices needed. The relevant parameters for appraising the suitability of irrigation water quality in terms of crop production are categorized based on the concentration of dissolved salt (salinity hazard), relative proportion of sodium ions to other cations (sodium hazard soil permeability effects), carbonate and bicarbonate anion concentration as related to calcium plus magnesium concentration (alkalinity) and concentration of specific elements that may be toxic (toxicity) (Ayers and Wescot, 1994). Many of the literature tend to evaluate water based on the first three criteria only because these are the most important to describe irrigation water quality.

This stems from the fact that ultimate effect of alkalinity is to sever the problem of sodicity. Nevertheless, the two problems are not exactly the same and should be independently addressed if alkalinity as a problem is anticipated. However, the quality of water, whether good or bad, is not sufficient to decide the suitability of water for agriculture. Several non-water factors must be considered in deciding the usefulness of water for a specific situation. These include soil texture and structure, internal soil drainage, gypsum and lime contents of the soil, salt and sodium tolerance of the crop, and irrigation method and management practice followed (Abrol *et al*., 1988).

2.8.1. Salinity hazard (TDS)

A salinity problem exists if salt accumulates in the crop root zone to a concentration that causes a loss in yield. In irrigated areas, these salts often originate from a saline, high water table or from salts in the applied water. Yield reductions occur when the salts accumulate in the root zone to such an extent that the crop is no longer able to extract sufficient water from the salty soil solution, resulting in a water stress for a significant period of time. If water uptake is appreciably reduced, the plant slows its rate of growth. The plant symptoms are similar in appearance to those of drought, such as wilting, or a darker, bluish-green color and sometimes thicker, waxier leaves. Symptoms vary with the growth stage, being more noticeable if the salts affect the plant during the early stages of growth. In some cases, mild salt effects may go entirely unnoticed because of a uniform reduction in growth across an entire field.

Salts that contribute to a salinity problem are water soluble and readily transported by water. A portion of the salts that accumulate from prior irrigations can be moved (leached) below the rooting depth if more irrigation water infiltrates the soil than is used by the crop during the crop season. Leaching is the key to controlling a water quality-related salinity problem. Over a period of time, salt removal by leaching must equal or exceed the salt additions from the applied water to prevent salt building up to a damaging concentration. The amount of leaching required is dependent upon the irrigation water quality and the salinity tolerance of the crop grown. Salt concentration increases with depth due to plants extracting water but leaving salts behind in a greatly reduced volume of soil water. In irrigable land, each subsequent irrigation pushes (leaches) the salts deeper into the root zone where they continue to accumulate until leached. The lower rooting depth salinity will depend upon the leaching that has occurred.

In irrigated agriculture, many salinity problems are associated with or strongly influenced by a shallow water table (within 2 meters of the surface). Salts accumulate in this water table and frequently become an important additional source of salt that moves upward into the crop root zone. Control of an existing shallow water table is thus essential to salinity control and to successful long-term irrigated agriculture. Higher salinity water requires appreciable extra water for leaching, which adds greatly to a potential water table (drainage) problem and makes long-term irrigated agriculture nearly impossible to achieve without adequate drainage. If drainage is adequate, salinity control becomes simply good management to ensure that the crop is adequately supplied with water at all times and that enough leaching water is applied to control salts within the tolerance of the crop.

Salinity, which is the measure of the total salt concentration in the water, is often the most important water quality parameter. It is usually expressed as lumped parameter-for instance, as electrical conductivity, ECiw (dS m-1) at 25°C or total dissolved salt (TDS) of irrigation water. Water with high total soluble salts content poses a salinity hazard in which high concentrations of salt in the soil result in a physiological drought condition. Excess soluble salts in the root zone restrict plant roots from withdrawing water from the surrounding soil, effectively reducing the plant available water (Bauder and Brock, 2001). The most commonly responsible electrolytes in causing salinity in water are the cations of Ca^{2+}, Na^{+}, K^{+} and the anion of HCO^{3-}, Cl and SO_4^{2-}. The contributions of CO_3^{2} is often time negligible but at times they may have to be taken in to account (Keren, 2000).

Table 3.Water classification by salinity

Water type	EC dS/m	TDS mg/litre
Non-saline water	< 0.7	< 500
Saline water	0.7–42	500–30 000
Slightly saline	0.7–3.0	500–2 000
Medium saline	3.0–6.0	2 000–4 000
Highly saline	> 6.0	> 4 000
Very saline	> 14.0	> 9 000
Brin	> 42	> 30 000

(FAO ,1985)

2.8.2. Sodicty hazared (SAR)

High concentrations of sodium in irrigation water can result in the degradation of well-structured soils. This will limit aeration and soil permeability to water, leading to reduced crop growth (Dehayr *et al*., 2006). Sodium in irrigation water can also cause toxicity problems for some crops, especially when sprinkler applied (Bauder *et al*., 2003). Soil dispersion is the primary physical process associated with high sodium concentrations (Bauder, 2001; Bauder and Brock, 2001). The high alkalinity associated with sodicity cause soil organic matter to disperse, which further weakens soil structure.

Root growth and seedling emergencies are restricted in the compacted and crusted sodic layers with dispersed clays. Poor aeration due to poor drainage will reduce the oxygen available to plant roots for respiration and will also cause carbon dioxide to build up in the soil, both further restricting root growth (Mehreteab *et al.*,2002).

The specific SAR value that precludes water from use as a source of irrigation depends upon a number of factors including the ECiw and clay composition of the soil. Generally speaking, however, when the SAR of irrigation water is higher than around 6-12 $mmolcl^{-1}$, the Na in the irrigation water can displace Ca from the exchange sites on soil clays and organic matter (Essington, 2004). The effect of sodium ions in the irrigation water in reducing the infiltration rate and soil permeability is dependent on the total salt concentration, as shown in Table 4.

Table 4. Potential irrigation problems due to sodium in irrigation water

Salinity level of irrigation water ds/m	No reduction	Slight reduction	Medium reduction	Sever reduction
	SAR	SAR	SAR	SAR
ECw = 0.7	<1	1-5	5-15	>11
ECw = 0.7-3.0	<10	10-15	15-23	>12
ECw = 3.0-6.0	<25	>25	No effect	No effect
ECw = 6.0-14.0	<35	>35	No effect	No effect
ECw = >14.0	No effect	No effect	No effect	No effect

Source Based on Rhoades,Oster and Schroer, 1982

2.8.3. Ionic balance

Magnesium is the 2nd most abundant cation found in highly saline water. However, in low ECiw, Ca^{2+} dominates over Mg^{2+}. Obviously, it can be stated that with an increase in EC iw, Ca:Mg ratio tends to decrease. It was believed in the past that, when the proportion of Ca^{2+}:Mg^{2+} is high, the sodicity hazard is low. However, this holds good so long as ECiw remains less than 4 dS m/l and Ca:Mg > 1. Harmful effects on soils appear when the ratio of Ca:Mg < 1. Occurrence of Mg^{2+} in higher proportion than Ca^{2+} tends to increase soil dispersion. Therefore, if the proportion of Mg^{2+} amongst the divalent ions is high, the soil dispensability hazard will be high (Alvaro, 2003). Magnesium is known to affect plant growth adversely mainly by reducing the Ca^{2+}assimilation; however, when high concentrations, of $Ca^{2+}$and Mg^{2+} occur together, there might not be any specific effect of Mg^{2+}on the plant growth.

In general the water quality classification for irrigation adopted by (FAO,1985) has proved most practical and useful in assessing water quality for on-farm water use. However, the suitability of water for irrigation also depends on other associated factors, such as the crop, soil, climate and management practices. Committee of Consultants, 1974 has given good interpretations of water quality for irrigation as indicated on Table.5 below.

Table 5 Interpretations of water quality for irrigation

Potential Irrigation Problem				Units	Degree of Restriction on Use		
					None	Slight to Moderate	Severe
Salinity (affects crop water availability)							
	EC_w			dS/m	< 0.7	0.7 – 3.0	> 3.0
	TDS			mg/l	< 450	450 – 2000	> 2000
Infiltration (affects infiltration rate of water into the soil. Evaluate using EC_w and SAR together)							
SAR	= 0 – 3	and EC_w	=		> 0.7	0.7 – 0.2	< 0.2
	= 3 – 6		=		> 1.2	1.2 – 0.3	< 0.3
	= 6 – 12		=		> 1.9	1.9 – 0.5	< 0.5
	= 12 – 20		=		> 2.9	2.9 – 1.3	< 1.3
	= 20 – 40		=		> 5.0	5.0 – 2.9	< 2.9
	Sodium (Na)						
	Surface irrigation			SAR	< 3	3 – 9	> 9
	Sprinkler irrigation			me/l	< 3	> 3	
	Surface irrigation			me/l	< 4	4 – 10	> 10
	Sprinkler irrigation			me/l	< 3	> 3	
	Boron (B)			mg/l	< 0.7	0.7 – 3.0	> 3.0
Miscellaneous Effects (affects susceptible crops)							
	Nitrogen (NO_3 - N)			mg/l	< 5	5 – 30	> 30
	Bicarbonate (HCO_3)						
	(overhead sprinkling only)			me/l	< 1.5	1.5 – 8.5	> 8.5
	pH				Normal Range 6.5 – 8.4		

University of California Committee of Consultants 1974.

2.8.4. AquaChem software

AquaChem is a software package developed specifically for graphical and numerical analysis and modeling of water quality data. It features a fully customizable database of physical and chemical parameters and provides a comprehensive selection of analysis tools, calculations and graphs for interpreting water quality data. The purposes of AquaChem, these powerful analytical capabilities are complemented by a comprehensive selection of commonly used plotting techniques to represent the chemical characteristics of water quality data. Each plot provides a unique interpretation of the many complex interactions between the groundwater and aquifer materials, and identifies important data trends and groupings (Calmbach, 2008).
AquaChem's data analysis capabilities cover a wide range of functionalities and calculations including unit conversions, charge balances, sample comparison and mixing, statistical summaries, trend analysis, and much more. AquaChem also has a customizable database of water quality standards with up to three different action levels for each parameter. Any samples exceeding the selected standard are automatically highlighted with the appropriate action level color for easily identifying and qualifying potential problems, (Schlumberger Water Services, 2008).

The plot types available in AquaChem include:

- Correlation plots: X-Y Scatter,Ludwig-Langelier, and Wilcox,
- Summary plots: Box and Whisker, Frequency Histogram, Quantile, Detection summary,
- Multiple parameter plots: Piper, Durov, Ternary, Schoeller,
- Time-Series plots (multiple parameters, multiple stations),
- Geothermometer and Giggenbach plot,
- Single sample plots: Radial, Stiff, and Pie,
- Thematic Map plots: Bubble, Pie, Radial and Stiff plots at sample locations.

Among these plots; Piper, Box and Whisker and Wilcox plots were used in this study

3. MATERIALS AND METHOD

3.1. Description of Study Area

This study was conducted at Modjo river catchment, which is located in East Showa administrative zone of Oromia Regional State at about 70kms, south east of Addis Ababa. The area covers about 2201.98km^2 and is bounded within 8°75'N-9°05'N latitude and 38°56'E 39°17'E longitude. The average elevation in the catchment ranges between (1591 to 3060) m above mean sea level at Modjo town and Mount Yerer respectively. The area has a bi-modal rainfall with a short rainy season from March to May and with a long rainy season from June to September. The mean annual temperature around Modjo is 19.91°C and the mean annual rainfall is 933mm. The relief of the study area is generally flatland with an undulation of some ridges and mountains like eastern part of Yerer and the catchment generally shows an eastward decrease in mean sea level. The water units found in the study area are Modjo and Gale Wemecha rivers. As to the geological set up, the area belongs to the Quaternary rocks of Pleistocene and Holocene, which is not yet differentiated to certain rock groups, and tertiary basalt of Paleocene-Oligocene-Miocene age of the plateaus adjoining to the rift.

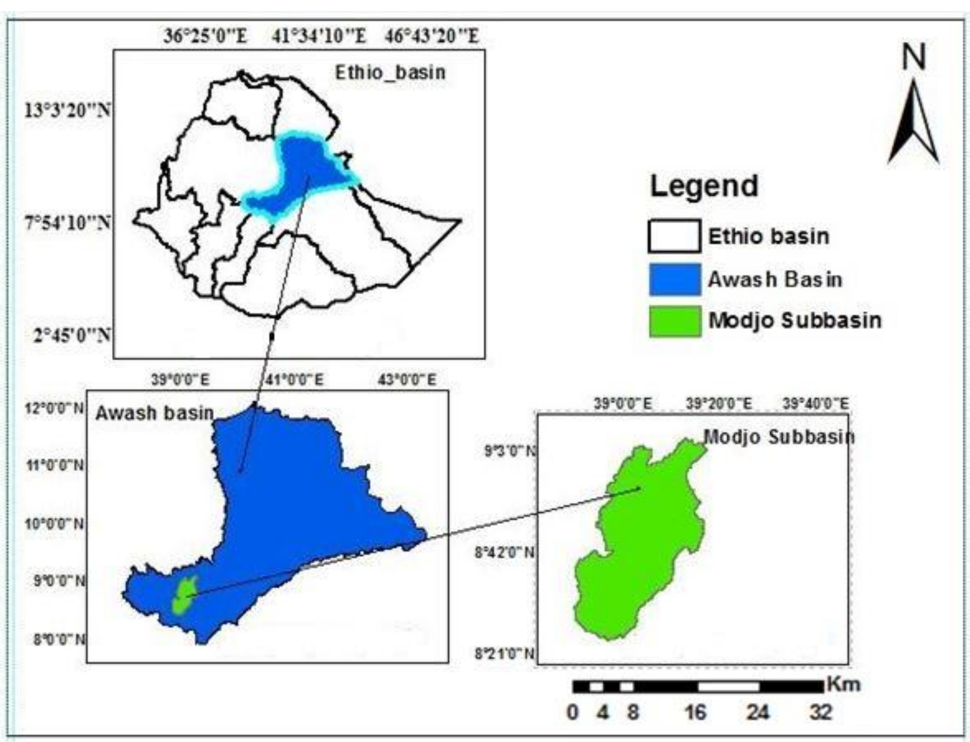


Figure 2.Location map of Modjo Subbasin

3.2. Material and Models

3.2.1. Materials used

The materials used were; GPS for taking geographic-coordinate values (altitude, latitude and longitude) of boreholes, and field points within the basin for accuracy assessment of the developed land use map, portable (pH) meter, buffer solution for pH meter calibration, and bottles for water sample collection, Spectrophotometer and flame photometer for determination of sulphat and sodium in laboratory respectively.

3.2.2. Models and software used

ArcGIS10.2 for all data processing, data management and data preparation as model required, ERDAS IMAGINE9.2 software to process the satellite images and to develop land use map of the study area, WetSpass model to estimate the long-term average spatially varying water balance components of the area and Aquachem 2012.5 software, for individual water sample analysis accuracy and reliability check; numerical analysis and graphical presentation of water quality data.

3.3. Data Source and Collection

3.3.1. Hydro-metrological data

Twenty eight years (1987-2014) climatic data were collected for all station from Ethiopian National Meteorological Services, processed and grid map of each was prepared using ArcGIS 10.2. Forty one static water level data for groundwater depth estimation in the subbasin was collected from MoWIE.

3.3.2. Spatial data

Digital Elevation Model (DEM) of Ethiopia was obtained from the Shuttle Radar Topography Mission (SRTM), to delineate the watershed, develop the topographic map and slope map of the study area, Enhanced Thematic Mapper Plus (ETM+) satellite imagery from the Landsat Organization home page was downloaded to develop land use classification of the study area; and soil map data-base of the Northeastern African countries that is prepared by the Food and

Agricultural Organization (FAO) of the United Nations to prepare the soil map of the study area.

3.3.3. Water quality data

For irrigation water quality analysis, groundwater samples were collected from well and borehole at different site within the subbasin. Beside this existing groundwater sample analysis results were collected from Awash basin authority and used in this study.

3.3. Model Input Data Preparation

WetSpass is a steady state models and, therefore, needs long-term average groundwater depth, long-term average meteorological data and spatial patterns of watershed physical maps.

The data required to do watershed simulation with WetSpass are, the climatic data (precipitation, reference evapotranspiration, temperature and wind speed), the catchment configuration data (groundwater depth, slope, elevation, and land use), soil data and boundary conditions (extent of area to be modeled). All input data must be in ASCII grid file format. Thus as a first step, a mask map should be prepared from the delineated catchment based on the DEM. All grid maps and parameter tables required as inputs for the WetSpass model were prepared with the help of ArcGIS software tools. The input files prepared as parameter tables were arranged in the database file format (dbf).

To run WetSpass model, nineteen input files are required. Fifteen of them were maps prepared in ASCII grid format of 120m cell size with 647 and 425 numbers of row and columns respectively. The remaining four files are attribute lookup tables inserted as dbf format. These input data are presented hereafter in detail.

3.3.1. Watershed delineation

The foremost important activity in the hydrological watershed modeling task is the delineation of the watershed boundary. To delineate subbasin from Ethio-DEM 30X30m resolution using ArcGIS10.2 the geographic locations of the basin, its longitude and latitude, were the bases to limit the area of interest during acquiring the DEM files from SRTM for this study.

Geographic x-y coordinates (492765m, 928900m) of the outlet point of the Modjo subbasin was added to the view as a database file (dbf) on the stream network on ArcGIS 10.2.

This outlet point is then converted into a shape file (shp) in the same view. The stream net view is zoomed in and the gauging point is properly placed on the derived streams net, by editing and dragging, just a little above the confluence watershed point. This shape file is then converted into a grid file and named "outlet" so that the delineation script can understand it. The streams.net shape file developed and the grid file named 'outlet' are then used as input to compile and run the "delineate" script. This has resulted in the Modjo subbasin with a total area of 2202 km^2. This mask map has been used to develop all other grid inputs for the model.

3.3.2. Land use/land cover

A traditional method of land cover mapping is inefficient and impractical for real-time global and regional land cover mapping. Satellite sensor images, also called remote sensing images, due to their synoptic view, are a viable source of gathering effective land cover information.

The satellite images for this particular study were acquired by the Landsat 7. The ETM+ images obtain from FAO Afrikaner database http://www.africover.org./index.htm.web site, with 30X30m resolution which is a FREE Global Orthorectified Landsat Data accessing site via FTP. Images for the study area are obtained at *path68 rows 53 and 54* acquired on the 27^{th} of January 2017, for winter season land use and on the 5^{th} of July 2017 for summer season land use. ArcGIS10.2 and ERDAS software were used to process the satellite images. Also the land use classes accuracy was based upon ground truth data obtained by GPS field collection within the basin.

Supervised image classification technique was applied for this study following the steps suggested by (Ronald, 2001) for supervised land use land cover classification as follows

i. Locate representative examples of each cover type that can be identified in the image (gcp),
ii. Digitize polygons around each ground control point (gcp),
iii. Assign a unique identifier name to each cover type after digitizing the polygons, analyze the pixels within the ground control point (gcp),
iv. Create spectral signatures for each of the cover types,

v. Classify the entire image by considering each pixel, one by one, comparing its particular signature with each of the known signatures by the help of classifiers.

3.3.3. Soil map

The soil map of the basin was acquired from the Soil and Terrain database for the northeastern Africa developed by FAO with 30X30m resolution (FAO, 2012). The percentage of the topsoil textures (coarse, medium and fine) has been used to look for the type of soil from the universal soil texture triangle.

3.3.4. Topography and slope

The topographic and slope map of the Modjo river basin has been derived from the Ethio-DEM 30x30m resolution using ArcGIS10.2 Spatial Analyst Tools.

3.3.5. Climatic data

There are two main seasons in the study area, namely summer and winter also locally called as Kiremt, Bega respectively. The main rainfall season is summer season ends only for four months from June to September. During this period the region receives more than 70% of the total annual rainfall. The study area is located within the main Ethiopian rift and mostly affected by the southerly and easterly Indian Ocean air currents, as a result the air currents supply rain with bimodal characteristics.

Twenty eight years (1987-2014) climatic data was used for six metrological stations selected for this study see Table 6 and the spatial areal rainfall distribution of each station is computed with Thiessen polygon using ArcGIS 10.2

Table 6.Rain gauge stations in Modjo subbasin

S.No	Gauge Station	Elevation (m)	Location		Period of data	Missed data (%)
			X(m)	Y(m)		
1	Chefedonsa	2392	512765	990959	1987-2014	10.5
2	Debrazeyit	1943	496335	985639	1987-2014	0.55
3	Modjo	1870	510904	950795	1987-2014	1.50
4	Koka	1597	516196	936243	1987-2014	0.60
5	Hombole	1670	484503	925367	1987-2014	2.50
6	Ejere	2233	531128	969873	1987-2014	11.3

Debrazeyit, Modjo, Koka and Hombole are class one metrological stations which include rainfall, max and min temperature, relative humidity, wind speed and sunshine hour whereas station Chefedonsa and Ejere are class two metrological stations which contain rainfall, max, min temperature and wind speed. Other parameters like relative humidity and sunshine hour were filled for missed period by normal ratio-method for those two stations.

3.3.5.1. Estimation of missed climate data

A number of methods have been proposed to estimate missing data (McCuen, 1989). In this study missing records of the rainfall was estimated by using normal ratio method which is recommended to estimate missing data in the subbasin where annual rainfall among stations differ by more than 10% (Dingman, 2002) for this study the variation among station shows 12%. This approach enables an estimation of missing rainfall data by weighting the observation at *N* gauges by their respective annual average rainfall values as expressed by equation 13 (Yemane, 2004).

$$P_X = \frac{1}{N}\left(\sum \frac{P_x}{P_i} * P_g\right) \quad (13)$$

where;

P_X= missing data,

P_x= the annual average precipitation at the gauge with the missing data,

P_i= annual average values of neighboring stations

P_g = monthly rain fall data in station for the same month of missing station

N = the total number of gages under consideration

3.3.5.2. Consistency analysis

To check consistency of recording data, double mass curve method was used as explained in Subramanya (2008). The accumulated totals of the gauge in question are compared with the corresponding totals for a representative group of nearby gauge station. If a rainfall record is a consistent estimator of the hydro meteorological occurrences over the period of record, the double-mass curve will have a constant slope. A change in the slope of the double mass curve would suggest that an external factor has caused changes in the character of the measured values. If a change in slope is evident, then the record needs to be adjusted, with either the early or later period of record adjusted.

3.3.5.3. Homogeneity test

To select representative meteorological stations, checking homogeneity of group stations is essential. The homogeneity of annual rainfall data for each station was tested using XLSTATA 2017 software by means of SNHT test (Standard Normal Homogeneity Test).

3.3.5.4. Precipitation

Long year records of daily rainfall values, from the national meteorological agency of Ethiopia, were available for all stations. The point data was processed using ArcGIS 10.2 interpolation process and the map, mean monthly values of precipitation for summer, winter and annual periods has been computed and prepared in ASCII file per model required.

3.3.5.5.Temperature and wind speed

The mean monthly temperature and wind speed for 28 years (1987-2014) was taken for all stations in the study area from National Meteorological Agency of Ethiopia.

3.3.5.6.Potential evapotranspiration

Estimation of potential evapotranspiration (PET)

The most general and widely used equation for calculating ETo is the Penman equation. In this study, Instat software has been used to compute the reference evapotranspiration (ETo); using the daily maximum and minimum temperatures, relative humidity, wind speed and solar radiation by applying FAO-Penman-Monteith equation.

$$\text{ETo} = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}\text{U}_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34\text{U}_2)} \qquad (14)$$

where,

ETo = Reference evapotranspiration (mm/day)

Δ = Slope of the saturated vapour pressure curve (kPa °C^{-1});

R_n = Net radiation (MJ m^{-2} day^{-1});

G = Soil heat flux density (MJ m^{-2} day^{-1});

T_m = Mean air temperature (°C) at 2.0 m;

U_2 = Average wind speed at 2.0 m height (m s^{-1});

e_s = Saturation vapour pressure (kPa) at temperature Tm;

e_a = Actual vapour pressure (kPa); ($e_s - e_a$) is the vapour pressure deficit (kPa); and

γ = Psychrometric constant (kPa $°C^{-1}$).

3.3.5.7.Groundwater depth

Representative static water level was taken from different boreholes for all stations (Appendix Table.6) and the average water level was used as groundwater depth input for the model. since, water balance computation using WetSpass would not be affected by groundwater levels deeper than 1m (Yibeltal, 2006).

3.3.5.8.Parameter tables

WetSpass is originally developed for conditions in the temperate regions; there should be some adjustment to use it for the case of Ethiopia. Summer and winter land-use, soil and runoff coefficient parameters are the four parameters tables used by WetSpass and be adjusted according to different area. They are connected to the model as attribute tables. The land-use attribute table includes parameters such as land-use type, rooting depth, leaf area index and vegetation height. The soil parameter table contains soil parameters such as textural soil class, and plant available water contents. The runoff coefficient attribute tables contain parameters for runoff classes of various land-uses, slope and runoff coefficient. These attributes tables allow for easy definition of new land-use and soil type as well as changes to each parameter value.

The original land use parameter tables for the model was developed based on land use types and characteristics from temperate regions, Europe in particular. Thus an attempt has been made, in this study, to modify the land use parameter table as the case in Ethiopia is different than what someone can find in Europe. Basic modification has been done on the land use parameters such as leaf area index, crop height, interception and percentage. In this regard, the vegetative area, bare area, impervious area, and open water area proportions of each land use class in Modjo subbasin has been defined based on the knowledge about the natural characteristics of the different land use types in the sub-basin; some of the seasonal land uses parameter values were readjusted as it has been used by (Tesfamichael *et al.*, 2010) for Ethiopia case. In addition, the parameters tables were adjusted by try and error through WetSpass watershed simulation repeatedly; this was done depending on the estimated groundwater recharge from well data and adjusting WetSpass recharge simulation value to the known ground truth spatial groundwater recharge obtained from the well data.

3.4. Methods Used for Water Quality Analysis

In this study the groundwater samples were collected from borehole of different site; in situ measurements such as; EC, pH, TDS and its corresponding temperature measurements were carried out in the field inventory using portable (pH) meters; major ions are analyzed in Sinana Agricultural Research Center Soil laboratory following the standard procedure.

3.4.1. Hydrogen ion activity (pH)

The pH of a solution measures the degree of acidity or alkalinity relative to the ionization of water sample. Pure water dissociates to yield 10^{-7} M of $[H^+]$ and $[OH^-]$ at 25°C; thus, the pH of pure water is neutral i.e. 7.

$$\text{pH water} = -\log [H^+] = -\log 10^{-7} = 7 \qquad (15)$$

Solutions with a higher $[H^+]$ than water (pH less than 7) are acidic; solutions with a lower $[H^+]$ than water (pH greater than 7) are basic or alkaline. The pH of any solution is a function of its temperature. One pH unit corresponds to 25 °C. Since pH values are temperature dependent, pH applications require some form of temperature compensation to ensure standardized pH values. For this study in-situ pH of groundwater and its corresponding temperature was measured using digital pH meters. The electrometric determination of pH by a pH meter is based on measuring the e.m.f. (milivolts) of a pH cell both a reference buffer and then with a test solution. The change in the potential difference at 25°C for 1 pH unit is 59.1 mV

3.4.2. Electrical conductivity (EC)

EC is a measure of the total concentration of ion. Conductance is expressed as micro Siemens, and is used as an indirect measure of TDS (mg/l). For most ground water, the EC value, in µS/cm corrected to 25°C, is about 50% greater than the TDS expressed as mg/l, and can be estimated according to:

$TDS = A \times EC$ (µS/cm)

$A \cong 0.55$ in bicarbonate waters, 0.75 in high sulphate waters and 0.9 in high chloride waters in some situations. In this study EC was directly measured by using digital EC meters.

3.4.3. Determination of carbonates and bicarbonates

Carbonate and bicarbonate ions in the sample were determined by titrating it with against standard sulphuric acid (H_2SO_4) using phenolphthalein and methyl orange as indicators in the laboratory.

3.4.4. Determination of calcium and magnesium (Edta Titrimetric Method)

The extent of sodium hazard in irrigation water is determined in terms of the sodium concentration in relation to the two useful divalent cations namely Ca^{++} and Mg^{++}. In this study the most common method complexometric titration using sodium salt of ethylene-diamine tetra acetic acid. (EDTA) were used for determination of calcium and magnesium in groundwater of the study area.

3.4.5. Determination of sodium on flame photometer

The concentration of sodium in water sample was determined by flame photometer.

3.4.6. Determination of chloride:

Chlorides being highly soluble are present in water but the amounts is often very low in natural water. However, their contents may be appreciable when the electrical conductivity is high. The determination of chloride is easily made by $AgNO_3$ titration (Mohr's titration) method in which silver reacts with chloride forming while AgCl precipitate in the presence of sulphuric acid. When all the chlorides are precipitated, potassium chromate (the indicator used) shows the brick red colour at the end point due to the formation of silver chromate.

Table 7. Chloride classification of irrigation water

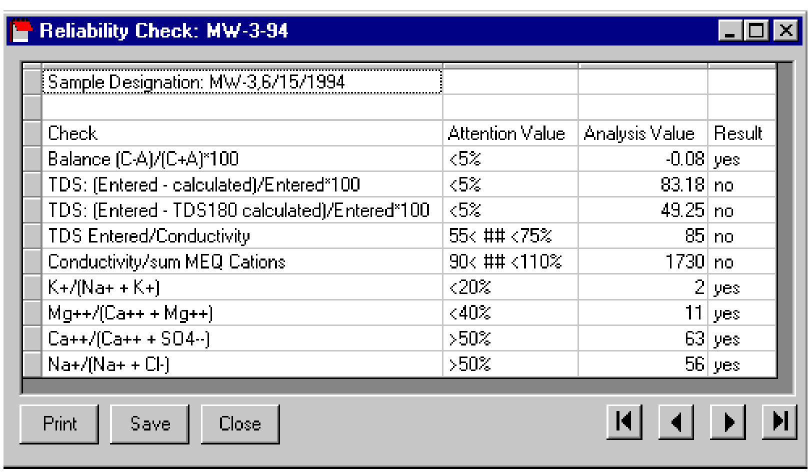
Chloride (mg/l)	Effect on crop
Below 70	Generally safe for all plants
70-140	Sensitive plants show injury
141-350	Moderately tolerant plants show injury
Above 350	Can cause severe problems

3.4.7. Determination of Sulphate on spectrophotometer

The sulphate content is determined by the extent of turbidity created by precipitated barium Sulphate suspension. Barium chloride is added to ensure fine and stable suspension of $BaSO_4$ at a pH of about 4.8. It also eliminates the interface of phosphate and silicate. Fine suspension of $BaSO_4$ is stabilized by Gum Acacia and the degree of turbidity measured by Spectrophotometer.

3.4.8. Accuracy of chemical analysis

The reliability check report helps to confirm the validity of the measured sample data. For these AquaChem 2012.5 software was used to evaluate the accuracy of the chemical analysis results for this study. Hence when this report is selected, the following **Reliability check: MW-3-94** window will appear on the software as shown Figure 3 below.



Check	Attention Value	Analysis Value	Result
Balance (C-A)/(C+A)*100	<5%	-0.08	yes
TDS: (Entered - calculated)/Entered*100	<5%	83.18	no
TDS: (Entered - TDS180 calculated)/Entered*100	<5%	49.25	no
TDS Entered/Conductivity	55< ## <75%	85	no
Conductivity/sum MEQ Cations	90< ## <110%	1730	no
K+/(Na+ + K+)	<20%	2	yes
Mg++/(Ca++ + Mg++)	<40%	11	yes
Ca++/(Ca++ + SO4--)	>50%	63	yes
Na+/(Na+ + Cl-)	>50%	56	yes

Figure 3. Reliability check window of AquaChcem software

This report provides a number of checks which can provide insight on the reliability of the water sample analysis. If the analysis value passes the test, then a **Yes** will be displayed in the Result column; if not, then a **No** will be displayed. Some attention values are displayed as "acceptable ranges". This means that the Analysis value must be within this range. If the analysis values are outside this range then the value will not "pass" this check, and the report will display a "NO", indicating that the sample did not pass this analysis check. If the calculated values are not within the attention values (i.e. the result is No), However; then this does not necessarily signify an error; it does mean however that there should be an explanation for the value.

3.4.9. Cluster analysis

Statistical techniques, such as cluster analysis, can provide a powerful tool for analyzing water-chemistry data. These methods can be used to test water quality data and determine if samples can be grouped into distinct populations (hydro-chemical groups) that may be significant in the geologic context, as well as from a statistical point of view.

Comparisons based on multiple parameters from different samples are made and the samples grouped according to their "similarity" to each other. This approach is commonly applied to water- chemistry investigations in order to define groups of samples that have similar chemical and physical characteristics because rarely is a single parameter sufficient to distinguish between different water types (Cüneyt *et al*., 2002). AquaChem 2012.5 software was used for GW cluster analysis in this study. Each cluster group is plotted on a Piper diagram which shows the relative contribution of major cations and anions on a mill equivalent basis to the total ion content of the water.

3.5. Water Quality Assessment

Quality criteria depend on the use of water for a particular purpose, and quality standards have to be maintained in water supply for different uses to avoid deleterious effects. In this section the quality of water were assessed from agricultural point of view.

3.5.1. Salinity hazard

The most influential water quality guideline on crop productivity is the water salinity hazard as measured by electrical conductivity (ECw). In this study the (EC) value obtained from measured during field inventory were compared against the standard value suggested by

(Bauder *et. al*., 2003) and the irrigation suitability recommendation for groundwater of study area was interpreted on the basis of this suggestion.

3.5.2.Sodcity hazard

The sodium hazard is typically expressed as the sodium adsorption ratio (SAR). This index quantifies the proportion of sodium (Na^{+}) to calcium (Ca^{++}) and magnesium (Mg^{++}) ions in a sample. General classifications of irrigation water based upon SAR values are presented in result section Table 20. Here again for this study the value suggested by *(Bauder et. al., 2003*) was used to compare and suggest suitability of groundwater for irrigation in the Modjo subbasin.

$$SARiw = \frac{Na}{\sqrt{\frac{Ca2+ + Mg2+}{2}}} \quad \text{all value in meq/l} \qquad (16)$$

4. RESULTS AND DISCUSSION

4.1. Spatial Data for Model Input

4.1.1. Watershed Delineation

Modjo subbasin with a total area of 2202 km² was delineated and this mask map has been used to develop all other grid inputs for the model

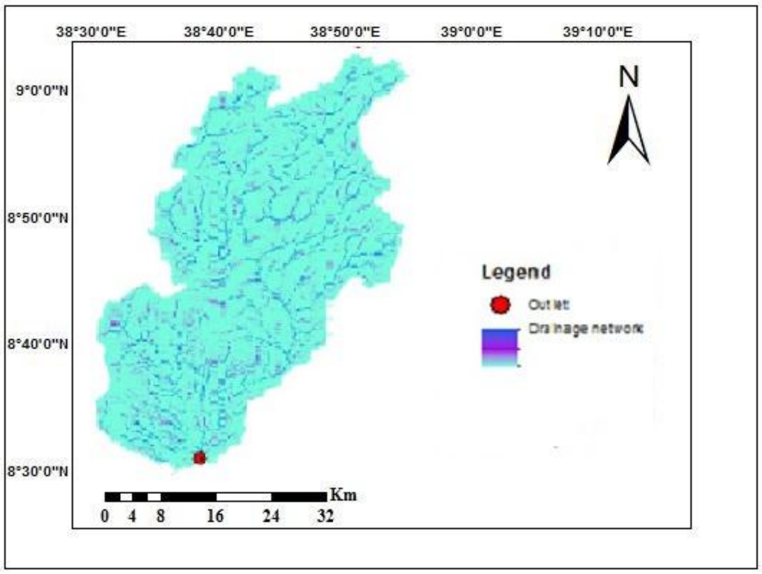


Figure 4 Drainage network of Modjo subbasin

4.1.2. Soil map

The subbasin is covered with four different soil types, 54% of silty clay, 34% of silty loam, 8% of clay and 4% of loam soil. The soil map of subbasin used in watershed simulation is shown in Figure 5 below

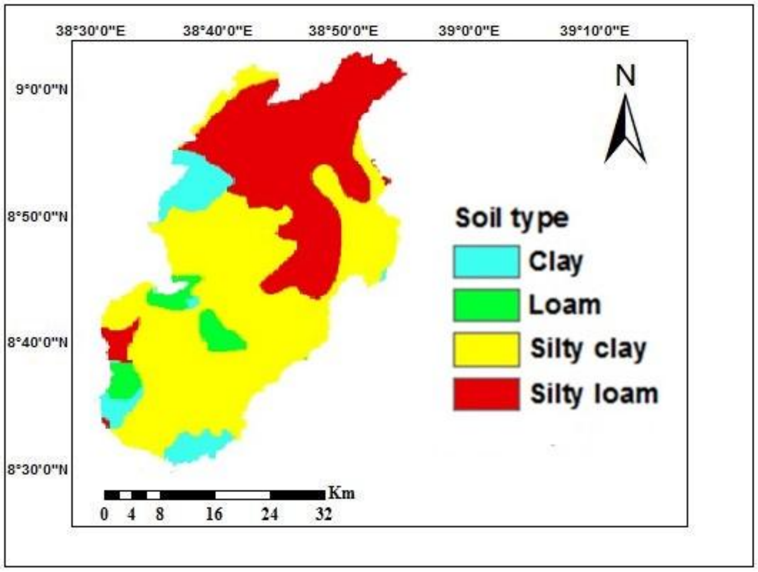


Figure 5. Dominant soil type of Modjo subbasin

4.1.3. Topography

Altitude in the basin increases from south to north and from west to east. The lowest point in the basin is located in the western edge and the highest in the north. The mean elevation of the basin is 2030 m with a standard deviation of about 273 m. This considerably large standard deviation explains the fact that the topography is rugged. Figure 6 below is the topographic grid map of study area used in the watershed simulation.

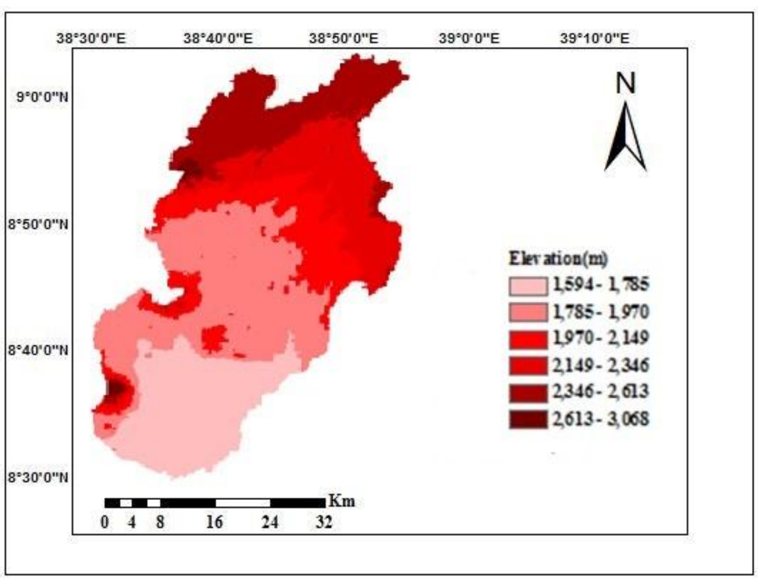


Figure 6.Topographic map of Modjo subbasin

4.1.4. Slope

The slope ranges from 0 to 52%, with 3% mean and standard deviation of 4%. Most of the agricultural area lies within the slope of 3-10%.

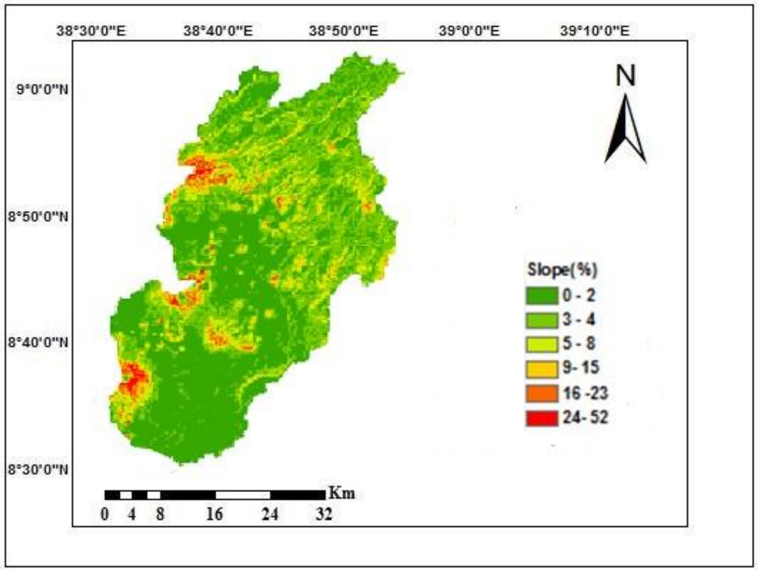


Figure 7.Slope map of Modjo subbasin

4.1.5. Land Use Classification

The land use classification of the study area were developed from landsat image as described in chapter three and finally the identity of each class is determined by a combination of experience and ground truth (i.e. visiting the study area and observing the actual cover types).The land use/cover type obtained accuracy estimation were justified by confusion matrix as shown on the table 8 below. Accordingly in Modjo subbasin agricultural land being the dominant which comprises 49.3% of the total subbasin area, grassland 16.5%, Tree & Shrub15% and Water body7%, Settlment11% are the prominent types of land use type.

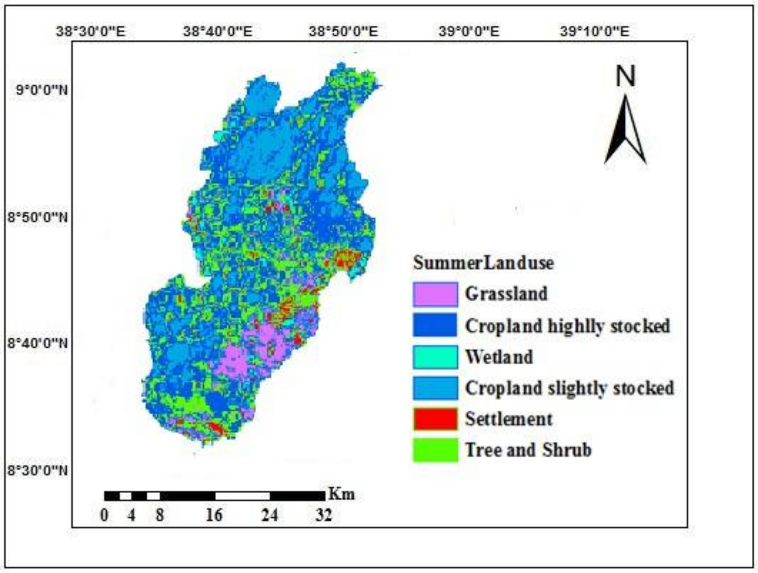


Figure 8. Summer land use map of Modjo subbasin

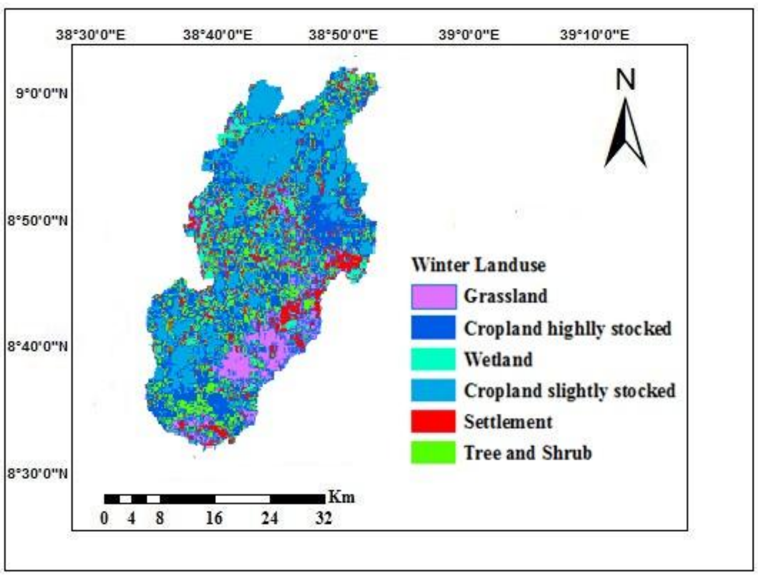


Figure 9.Winter land use map of Modjo subbasin

4.1.5.1. Accuracy assessment

A total of 164 points (locations) were created in the classified image of the study area. The accuracy assessment cell array reference column was filled according to the best guess of each reference point.

Table 8. Theoretical confusion matrix of LULC classification.

S.NO	Land use/Cover	Grassland	Cropland highly stocked	Wetland	Cropland slightly stocked	Settlement	Tree and shrubs	Total	Correct sampled
1	Grassland	12	2	0	3	3	5	25	19
2	Cropland highly stocked	5	17	0	5	0	2	29	22
3	Wetland	0	0	7	1	1	0	9	9
4	Cropland slightly stocked	7	12	1	12	2	3	37	28
5	Settlement	2	0	2	1	31	2	38	30
6	Tree and shrubs	3	2	1	3	4	13	26	21
	Total	**29**	**33**	**11**	**25**	**41**	**25**	**164**	**129**

Table 8.Shows the relationship between ground truth data and the corresponding classified data obtained through confusion matrix report. The overall classification accuracy = No. of correct points/total number of points = $\mathbf{\frac{129}{164} = 79.7\%}$

4.1.5.2. Adjusted land use parameter table

The land use parameter table was modified and land use parameter tables for Modjo subbasin summer and winter seasons was developed. The modified summer and winter land use parameter tables have been used to run WetSpass for the subbasin modeling processes. The highlighted portion on Table 9 and 10 below indicates the amended parameter table values for the study area.

Table 9.Summer land-use parameter table for Modjo subbasin

NUMBER	LUS_TYPE	RUNOFF_VEG	NUM_VEG_RO	NUM_IMP_RO	VEG_AREA	BARE_AREA	IMP_AREA	OPENW_AREA	ROOT_DEPTH	LAI	MIN_STOM	INTERC_PER	VEG_HEIGHT
1	City center	grass	2	0	0.7	0	0.3	0	0.3	2	100	10	0.2
21	Crop land	crop	1	0	0.9000	0.0000	0.2000	0.0000	0.4000	2.00	180.00	35.00	0.7000
23	Grass land	grass	2	0	0.7000	0.0000	0.2000	0.0000	0.3000	2.00	100.00	10.00	0.2000
33	Forest	forest	3	0	0.8000	0.0000	0.2000	0.0000	2.5000	7.50	375.00	50.00	10.0000
36	Shrub land	grass	2	0	0.8000	0.0000	0.2000	0.0000	0.6000	6.00	110.00	42.00	2.5000
52	lake	open water	0	0	0.001	0.000	0.05	1	0.05	0.00	110	5.00	0.001

Table 10.Winter land-use parameter table for Modjo subbasin

NUMBER	LUS_TYPE	RUNOFF_VEG	NUM_VEG_RO	NUM_IMP_RO	VEG_AREA	BARE_AREA	IMP_AREA	OPENW_AREA	ROOT_DEPTH	LAI	MIN_STOM	INTERC_PER	VEG_HEIGHT
1	City center	grass	2	0	0.4	0.2	0.05	0	0.3	2	170	20	0.2000
21	Crop land	crop	1	0	0.2000	0.4000	0.4000	0.0000	0.3500	2.00	180.00	20.00	0.6000
23	Grass land	grass	2	0	0.3000	0.2000	0.0500	0.0000	0.3000	2.00	170.00	20.00	0.2000
33	Forest	forest	3	0	0.8000	0.1000	0.1000	0.0000	2.0000	4.50	350.00	38.00	10.0000
36	Shrub land	grass	2	0	0.2000	0.8000	0.0000	0.0000	0.6000	0.00	110.00	30.00	2.0000
52	lake	open water	0	0	0.001	0.000	0.05	1	0.05	0.0	110	5.00	0.001

4.2. Climatic Data for Model Input

4.2.1. Areal rainfall distribution

To compute spatial areal rainfall, Theissen polygon method was used in ArcGIS environments and the gauge weights developed for sub-catchments are presented in Table 11.

Table 11. Theissen gauge weights for Modjo subbasin

S.No.	Rainfall stations	Area weight (km^2)	Gauge weight (%)
1	Chefedonsa	450	20
2	Debrazeyit	694	32
3	Modjo	510	23
4	Koka	173	8
5	Hombole	142	6.4
6	Ejere	233	10.6

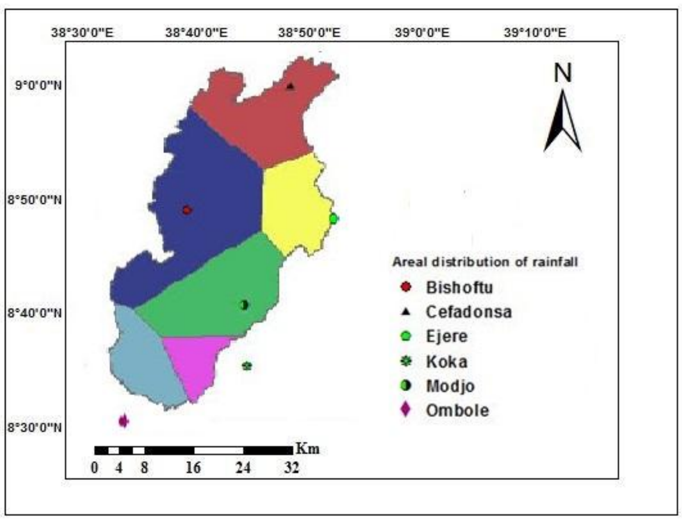


Figure 10.Theissen polygon developed for Modjo subbasin

4.2.2. Data consistency

Double mass curve method was used as explained in chapter three to check consistency of recording data; unfortunately, all the selected stations in this study were consistent; there was no need of further correction. The consistency of cumulative rainfall of neighboring station against annual cumulative rainfall of base station is shown on Figure.11 below

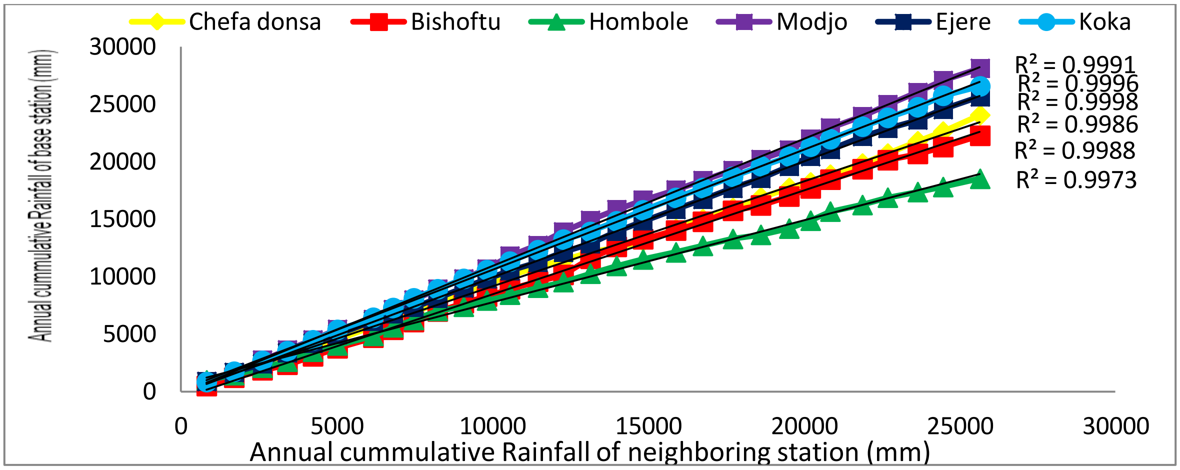


Figure 11.Consistency test graph for all station

4.2.3. Homogeneity test

From SNHT as shown in the Table 12 the greater p-value from significance level alpha and the horizontal broken line shown in the graph Appendix Figure.1 implies homogeneity of rainfall station.

Table 12 Summary statistics of homogeneity test

S.No.	Station name	Variable	Obs	Mean	SD	*To*	P-value	Alpha
1	Chefedonsa	Prec	28	1152	211.79	6.93	0.13	0.05
2	D/zeyit	Prec	28	930	194.79	3.39	0.46	0.05
3	Modjo	Prec	28	918	97.48	6.19	0.11	0.05
4	Hombole	Prec	28	772	145.77	5.92	0.12	0.05
5	Koka	Prec	28	786	189.42	5.13	0.13	0.05
6	Ejere	Prec	28	998	201.33	6.51	0.42	0.05

To = statistic derives, SD= standard deviation, prec= precipitation,Obs= observation

4.2.4. Precipitation

The mean annual precipitation value calculated for the subbasin is 933mm and its grid map used in the model for watershed simulation is shown on Figure 12 below.

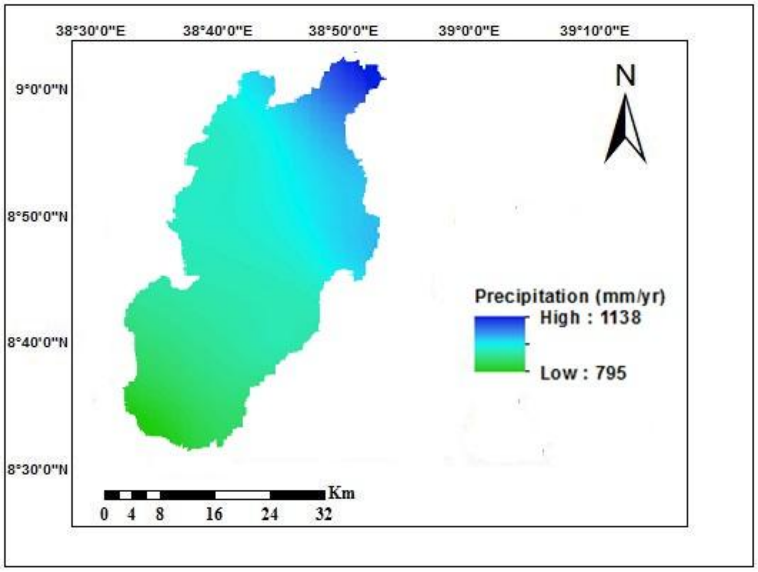


Figure 12.Average annual precipitation of Modjo subbasin

4.2.5. Temperature

The study area has an average temperature of 19.91°C with a minimum temperature of 11.6°C and a maximum temperature of 29.2°C. Maximum temperature values were obtained in the months of May and minimum temperature was recorded in the month of August and it has generally been observed that the average annual temperature decreases with an increase in altitude.

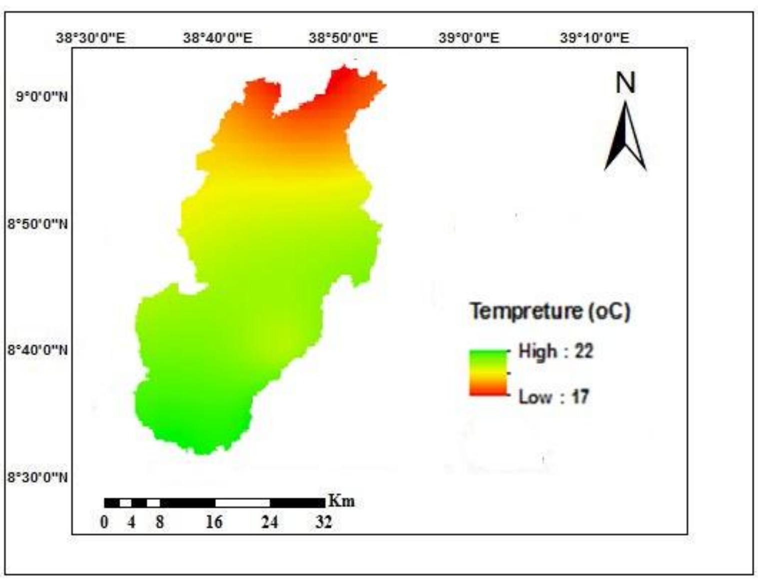


Figure 13. Average annual temperature of Modjo subbasin

4.2.6. Evapotranspiration

Often a value for the potential evapotranspiration is calculated at a nearby climate station on a reference surface, conventionally short grass. This value is called the reference evapotranspiration (ETo) which is equal to PET. For this simulation PET grid map shown on Figure 14 is used as input for the model.

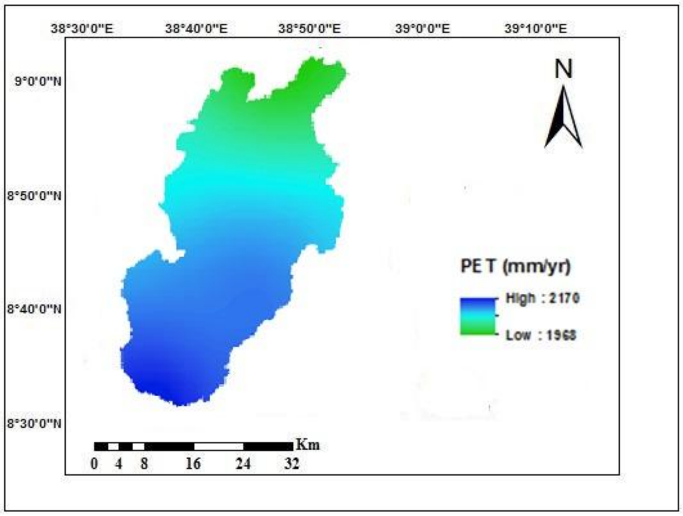


Figure 14. Average annual PET of Modjo subbasin

4.2.7. Wind speed

The mean monthly wind speed of the area measured at two meters above the ground varies from 1.6 to 2.6m/s. with maximum values observed in the months between February to May and minimum values in the months of August and September.

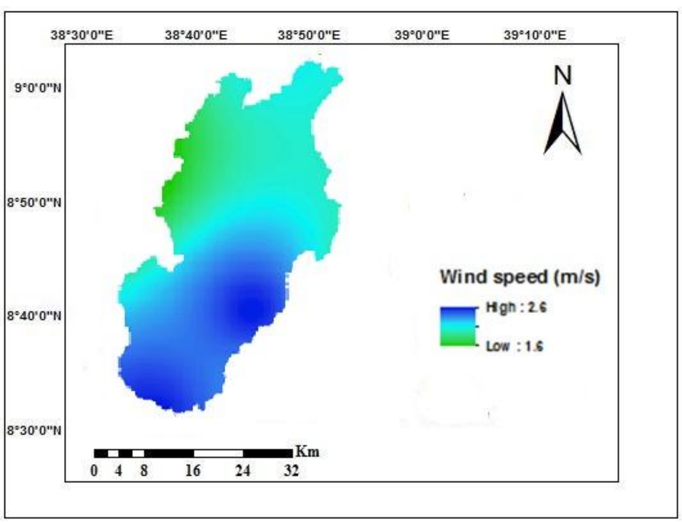


Figure 15. Average annual wind speed of Modjo subbasin

4.2.8. Groundwater depth

In this study, an average value of groundwater level was used for all station from data collected and assumed as the groundwater depth for both summer and winter seasons

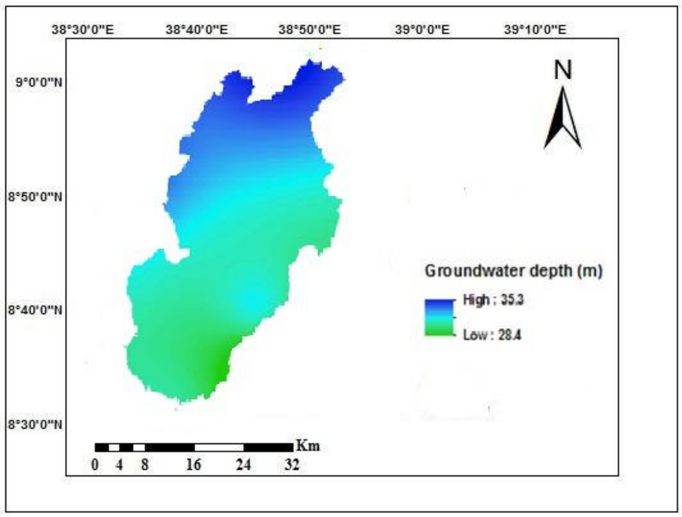


Figure 16.Average groundwater depth of Modjo subbasin

4.3. Water Balance Analysis

Water balance represents the hydrological gains and losses of a given system. For this study WetSpass modeling was applied and all water balance computations were carried out from model output as follow.

4.3.1. Evapotranspiration

The WetSpass model calculates the total actual evapotranspiration as a sum of the evaporation of water intercepted by vegetation, the transpiration of the vegetative cover and the evaporation from the bare soil between the vegetation.

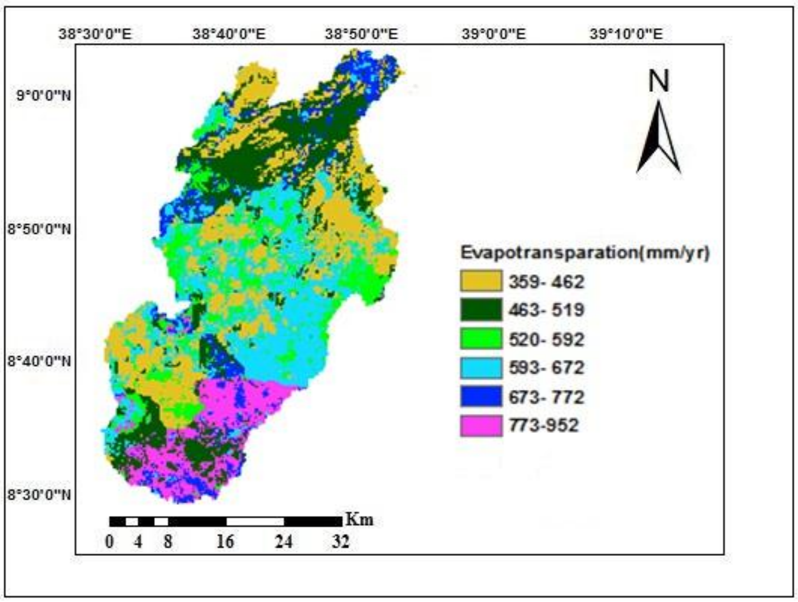


Figure 17 Simulated annual evapotranspiration with the WetSpass model for Modjo subbasin

The simulated average minimum and maximum annual evapotranspiration of the catchment are 359 mm and 952 mm respectively, with 686 mm mean and standard deviation of 141 mm distribution.

The average evapotranspiration accounts more than 73.5% of the total annual rainfall. This shows that evapotranspiration is the main processes by which water is lost in the catchment. This is attributed to the high rates of radiation and the persistence of strong dry Westerly winds coming from the Awash depression. The evapotranspiration is largely determined by the solar radiation, which is fairly constant between years. As a result evapotranspiration varies little from year to year, especially in the dry season. About 77% of the total annual evapotranspiration is lost during summer season while the rest 23% is released in the winter season. This variation occurs due to difference in precipitation within the two seasons.

According to Behailu; 2007, the average annual actual evapotranspiration of Modjo river catchment is about 650.33 and 789.47 mm with Thornthwaite and Turc method respectively; (Getachaw, 2007) reports similar results for the nearest watershed Welanchiti area, annual actual evapotranspiration, from Turc method gives value of 697 mm. Thus 952 mm maximum and 686 mm average annual evapotranspiration, simulated by WetSpass for Modjo river catchment, is reasonable.

WetSpass has also simulated constituents of evapotranspiration, i.e. interception, soil evaporation and transpiration. Interception is the part of the rainfall that is intercepted by the earth's surface and subsequently evaporated. It can take place by vegetal cover and depression storage in puddles and in land formation such as rills and furrows. Interception can amount up to 15-50% of precipitation, which is significant part of the water balance. For this subbasin 260 mm and 15 mm interception was simulated by WetSpass as maximum and minimum respectively and the mean was 177 mm which accounts about 25% of the mean evapo-transpiration.

WetSpass also simulate 447 mm and 52 mm maximum and minimum transpiration with 290 mm mean value, soil evaporation of 375 mm maximum and 12 mm minimum with mean of 220 mm was simulated for the subbasin. The map of three constitute of evapotranspiration is shown in Appendix Figure (2-4).

The relation between transpiration and soil evaporation depends strongly on the density of the plant cover, expressed by the leaf area index (LAI). In general, soil evaporation decreases rapidly with increasing LAI while the opposite is true for transpiration (Merta *et al.*, 2002). Since WetSpass determines the total evapotranspiration as the sum of the evaporation from soil, intercepted water and transpiration, it is obvious that the evapotranspiration varies spatially according to the land use class and soil types.

Since the catchment is located in one of the sub-humid regions of Ethiopia, soil evaporation is less important than transpiration. The simulated result also supports this fact that, as can be understood; evapotranspiration in the catchment is mostly in the form of transpiration and hence it is less dependent on the soil type.

4.3.2. Surface runoff

According to Batelaan (2007), surface runoff is dependent on the availability of vegetation, soil type and slope of the subbasin. Hence the surface runoff Modjo river catchment varies spatially with topography and other catchment characteristics. Rugged topography and silty clay, silty loam soil dominated the lands and gave the largest amount of runoff in the catchment. This is due to a lower concentration time of overland flow for rugged topographic surface and the lesser infiltration capacity of the soil type.

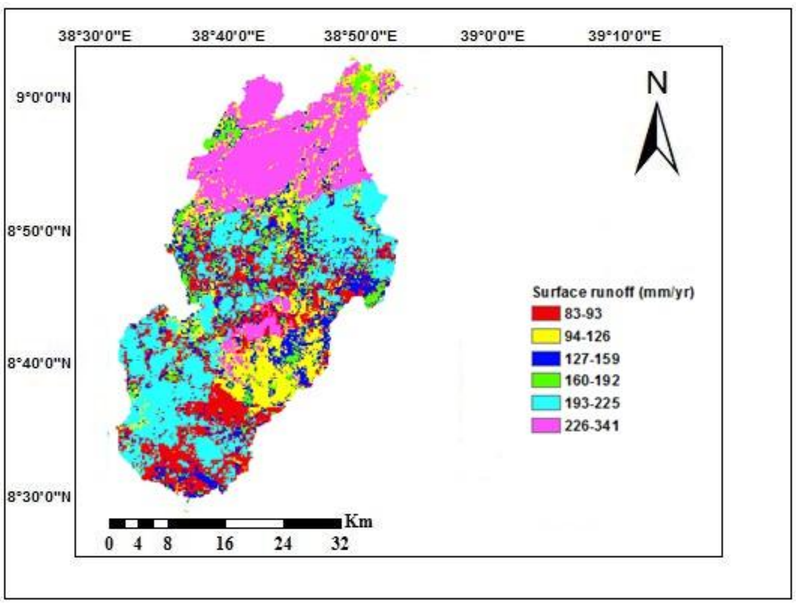


Figure 18.Simulated annual surface runoff with the WetSpass model for Modjo subbasin

The simulated annual runoff varies from 83 mm to a maximum of 341 mm with a mean and standard deviation of 164 mm and 66.89 mm respectively. This accounts about 17.6% of the total annual precipitation. Considering the (2202 km^2) area of Modjo river catchment, average annual surface runoff will be 361Mm^3. The rainfall exceeds the infiltration capacity of the soil during the wet season, this leads to high surface runoff. Equivalently about 81% of the surface runoff occurs during the wet months (June to September) while the remaining 19% occurs during the dry months (October to May) from the catchment. Behailu; 2007, applied runoff coefficient method and revealed that the annual surface runoff of Modjo river catchment of area 1506 km^2 is 130 mm, also the research conducted in the nearest watershed Welanchiti area by (Getachaw, 2007) reveals the annual surface water out flow, estimated using runoff coefficient methods from an area of 780 km^2 resulted 129.5 Mm^3. Thus 83 mm minimum and 341 mm maximum annual surface runoff, simulated by WetSpass for Modjo river catchment, is reasonable.

4.3.3. Groundwater recharge

Recharge is promoted by natural vegetation cover, flat topography, permeable soils, a deep water table and the absence of confining beds. The WetSpass model determines the long term average spatially distributed recharge as a spatial variable dependent on the soil texture, landuse, slope and meteorological conditions.

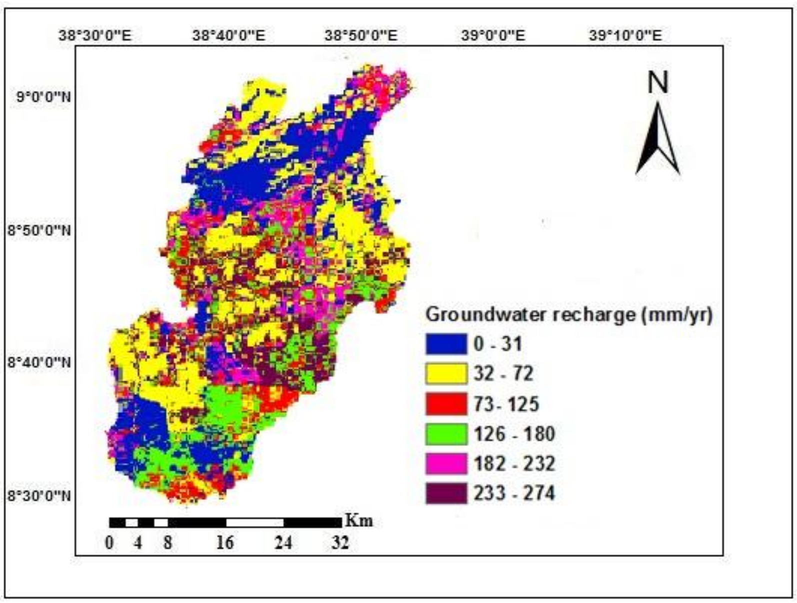


Figure 19.Simulated groundwater recharge with the WetSpass model for Modjo subbasin

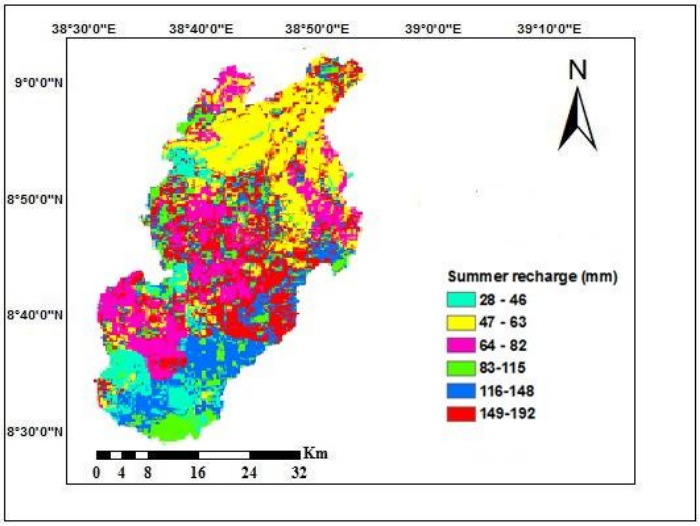


Figure 20. Simulated summer groundwater recharge with theWetSpass model for Modjo

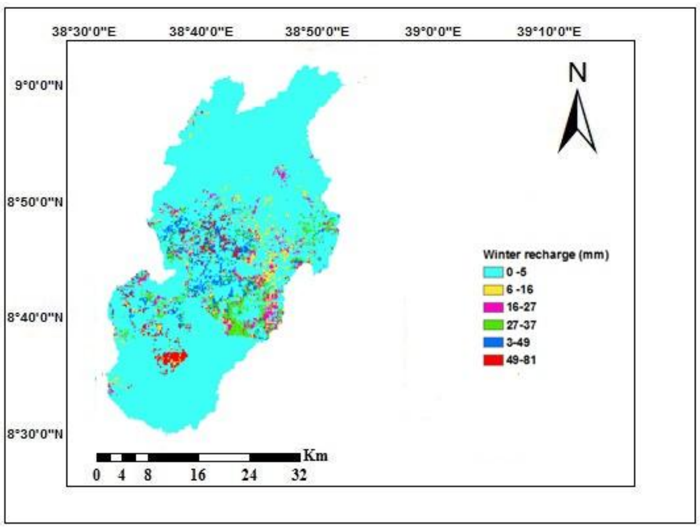


Figure 21.Simulated winter groundwater recharge with the WetSpass model for Modjo subbasin

The resulting groundwater recharge from WetSpass for the present land use ranges from about 274 mm/yr to zero, with an average value of 83 mm/yr, which is about 8.9% of the mean annual precipitation, and standard deviation of about 32 mm. About 70% of the annual ground water recharge of the subbasin occurs during the wet season (summer), and the remaining 30% in dry season (winter) specially (April and May).Thus an average of 183 Mm^3 of ground water will be recharged per year for total catchment area. For the study conducted on groundwater potential of Ada'a Becho plain, annual groundwater recharge contributed from Modjo river to Ada'a Becho plain is 85 mm and 153 Mm^3 (Semu, 2012), which is almost comparable with WetSpass result. Similarly (WAPCOS, 1990) report 7% of annual groundwater recharge for Awash basin for the mean annual rainfall of 850 mm. (Ayenew and Alemayehu; (2001) also indicate the groundwater recharge as (50 –150) mm for much of Northern and northwestern highlands, central main Ethiopian rift and southern and eastern regions between the rift plain. Therefore the result simulated by WetSpass for the Modjo river catchment is within the previous study range and reasonable.

4.4. Seasonal Result Analysis

The potential evapotranspiration in the catchment is larger in winter (66.5%) than in summer (33.5%). This is apparently associated with longer sunshine hour and larger wind speed values in winter than in summer. However, the simulated actual evapotranspiration in winter is lower for most of the land use types than for summer. This is due to the lower rate of soil evaporation, transpiration and interception in winter due to insufficient rainfall to meet the potential demands. During summer the evapotranspiration is so excessive that it causes negative recharge in some parts of the catchment, in winter since the rainfall is not excessive to create too much runoff and also due to the fact that the soil is dry the groundwater recharge has found to be larger than summer. However, the total recharge in the catchment is larger in summer due to the fact that high rainfall in this season.

Table 13. Mean seasonal and annual WetSpass hydrologic output for Modjo river catchment

Parameters (mm)	Summer (mm)	Winter (mm)	Annual (mm)
Precipitation	717	216	933
Runoff	133	31	164
Evapotranspiration	526	160	686
Interception	157	24	181
Transpiration	249	33	282
Soil evaporation	120	103	223
Recharge	**58**	**25**	**83**

4.5. Water Balance Analysis by Land Use and Soil Type

Since WetSpass determines the total evapotranspiration as the sum of the evaporation from soil, intercepted water and transpiration, it is automatic that the evapotranspiration varies spatially according to the land use class and soil types. Water bodies (936 mm) and trees and shrub (756 mm) land use is the land cover types where the simulated evapotranspiration is the highest followed by grassland (675 mm) due to high evaporation from open water surface and transpiration rates from vegetation respectively, while highland areas of the cropland and settlement with lower evaporation and transpiration, because large areas of this land use is found to be hilly stone covered impervious surfaces and relatively low temperature areas.

The WetSpass model uses the runoff coefficient method for the estimation of surface runoff, whereas this parameter is a function of vegetation type, soil texture and slope. Similarly, the highest runoff rate occurs from the agricultural lands (290 mm) and settlement (233 mm) due to disturbed soil and impervious surfaces in these land-use classes respectively. Plain areas, more silty loam and silty clay soil covers, and areas with vegetation cover have relatively lower runoff rates in the catchment.

Groundwater recharge is generally found to be much higher in non vegetated land-uses than in vegetated land-uses (Gee *et al.*,1974) and is greater in areas of annual crops and grasses than in areas of trees and shrubs (Prych,1989). In this simulation, from WetSpass water balance of the catchment high recharge occurs from grassland on the plain areas (155 mm). This land-use unit has lower runoff and evapotranspiration compared to the cultivated land and tree and shrub; secondly the groundwater recharge was high on agricultural land (143 mm), because this land unit is bare and the soil is dry at the beginning of the rainy season having low transpiration; and drying up of soil favors more water infiltration contributing to recharge.

Table 14. Average water balance in land use difference

Land use group	Average water balance component (mm)			
	Precipitation	Evapo transpiration	Runoff	Recharge
Grass land	923	675	93	155
Cropland highly stocked	943	555	245	143
Cropland slightly stocked	913	550	290	73
Tree and Shrub	956	756	120	80
Settlement	923	642	233	48
Water bodies	936	936	0	0

The evapotranspiration seems not to show a clear pattern with soil texture in general, it is less dependent on the soil type in the basin.

The highest runoff is generated from silty loam and clay soil located in the high slope and high rainfall area. This is due to high rainfall and rugged topographic nature of the area. The runoff rate decreases as the soil gets lighter loam and silty clay; however, the runoff difference in this simulation is more affected by rainfall amount and topographic effect than soil type.

High values of groundwater recharge are observed in the grassland and cropland with silty loam, silty clay and loam soils. This is due to relatively good permeability of the soils and gentle slope. Areas where clay soil is dominant yield the lowest rate of recharge (36 mm). However, the variation of recharge with land use type is more pronounced than its variation with soil type.

In general, the annual results analysis reveals that evapotranspiration is the most important hydrologic process in the basin, by which most of the precipitation is lost, than surface runoff and recharge.

Table 15.Average water balance in soil type difference

Soil texture group	Average water balance component (mm)			
	Precipitation	Evapo transpiration	Runoff	Recharge
Silty clay	939	743	105	91
Silty loam	967	628	208	131
Clay	932	698	198	36
Loam	893	675	145	73

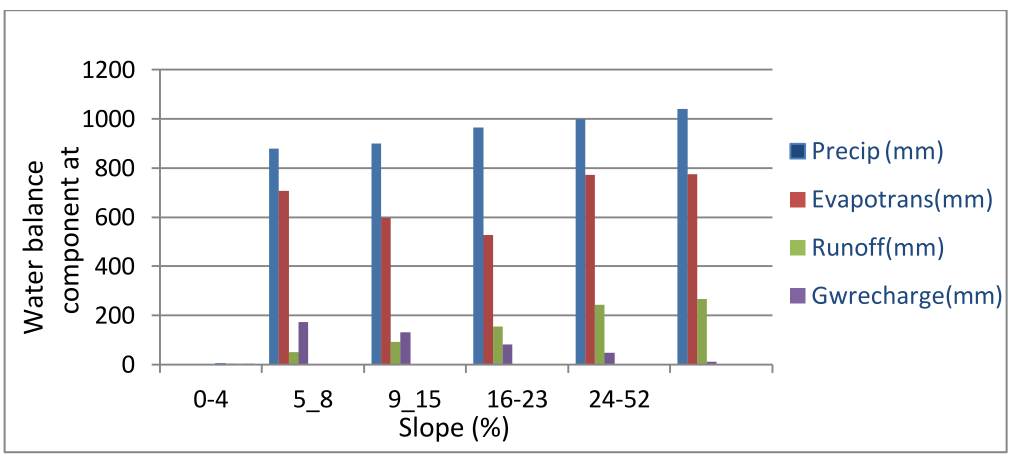


Figure 22.WetSpass simulation for average runoff, actual evapotranspiration, and recharge for different slop classes in Modjo subbasin

4.6. HYDROCHEMISTRY

The analytical results of water sample were presented spatially to allow visualization of the water types and their relationships. In order to understand the groundwater flow system and interaction among waters of different provenance, hydro-chemical distribution maps of different parameters have also been prepared. The various types of display and discussion on the hydrochemistry of the study area are presented as follow:

4.6.1. Physiochemical parameters

4.6.1.1. Hydrogen ion activity (pH)

The pH of the water samples obtained from most of the samples varies from 6.88 to 8.3. Water bicarbonate is dominant and in general the water of the study area has an alkaline pH. Alkalinity increases from north east towards the south direction (high rainfall to low rainfall area) of the catchment as shown on Figure 23 below, this is because high rainfall contributes to the formation of acidity lowering the alkaline concentration in the groundwater.

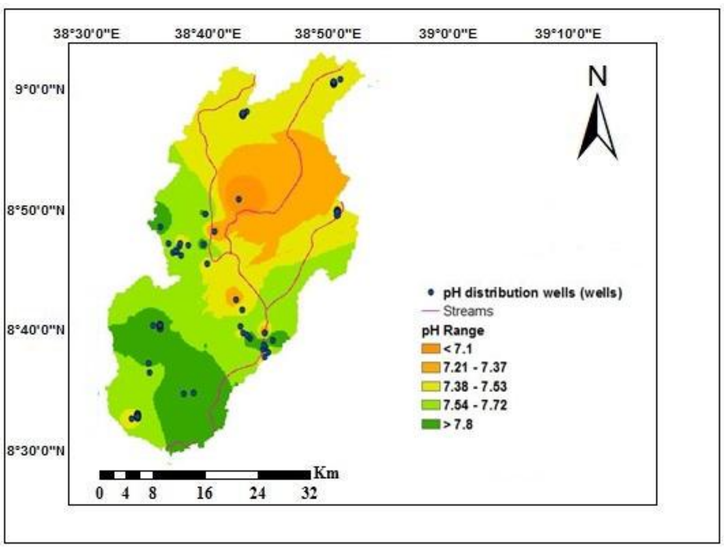


Figure 23.Spatial variation of pH value within the catchment

4.6.1.2. Total dissolved solid (TDS)

Total Dissolved Solids concentration is approximately equal to the sum of the concentrations of all dissolved ions. This ion can include carbonate, bicarbonate, chloride, sulphate, phosphate, nitrate, calcium, magnesium, sodium, organic ions, and others. From the water quality analysis result of the study area the TDS of study area ranges from (175-750)ppm. It increases towards ground water flow direction along the axis of the valley. This implies that as the water goes from the highland through fractured and unconsolidated sediments it acquires dissolved solids more.

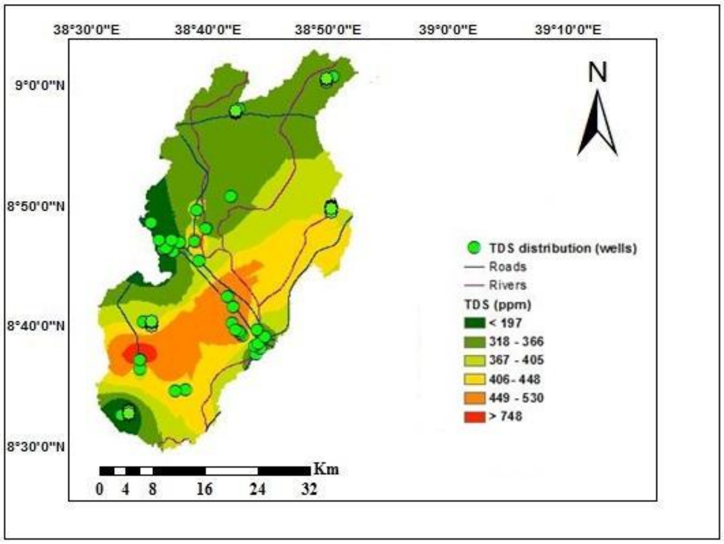


Figure 24.TDS map of Modjo subbasin

4.6.1.3. Electrical conductivity (EC)

The conductivity of the groundwater in the area ranges from 351µS/cm to 1038µS/cm in a both well and borehole. Higher conductivities are observed in wells located in the South eastern along the depression of the subbasin. This increase in conductivity towards the axis of the valley could be associated with the geology, the ground water flow direction and possible evaporation. According to (Freeze and Cherry,1979), dissolved solid concentrations in groundwater increase along flow paths, from the surface to the saturated zone and through the aquifer, due to the dissolution of minerals. Similarly, the groundwater of the catchment was found to flow from the north eastern escarpment towards the south eastern floor contributing to increase in dissolved solid along its flow path.

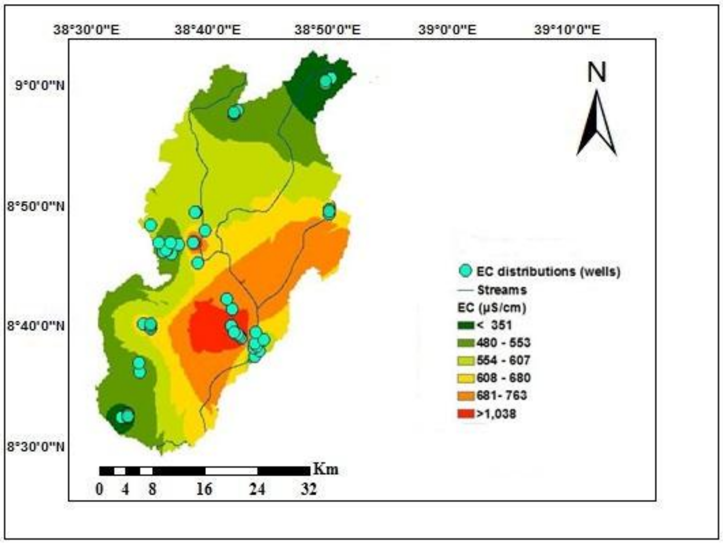


Figure 25.EC map of Modjo subbasin

Electrical conductivity is the ability of a substance to conduct electric current (Hem, 1985). The presences of charged ionic species in water make it conductive. In other words, EC is a measure of the total concentration of ion. Even though conductivity may not correlate directly to concentration, in this study the water quality results show that electrical conductivity (EC) and total dissolved solid (TDS) have a good correlation of TDS = 0.847EC – 121.2 with R^2 = 0.8094 see (Figure 26).

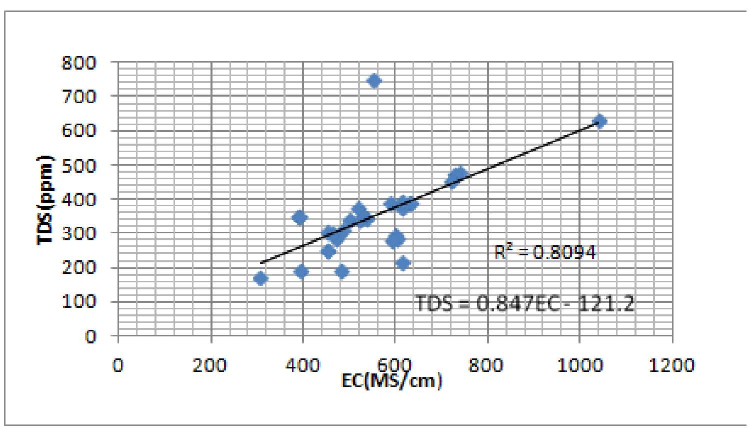


Figure 26.TDS – EC correlation for the water sample

4.7. Water Sampling and Accuracy of Chemical Analysis

Groundwater samples were collected from Wells and boreholes during the field visit in January 2017. Beside this existing groundwater sample analysis results were collected and used in this study. A total of 34 new samples were collected and analyzed during field work and 7 existing chemical analysis results were acquired from Awash basin authority (see Appendix Table 7). The location of the water samples are indicated in Figure 27 and 30 most of the samples were taken from the town settlement areas and around twelve samples were taken from the wells and boreholes found in rural (farm) areas. This is due to the borehole distribution of the subbasin.

4.7.1. Reliability check

The reliability check report helps to confirm the validity of the measured sample data. For these AquaChem 2012.5 software was used to evaluate the accuracy of the chemical analysis results for this study. Accordingly, all samples were subjected to this check and some result is tabulated on Appendix Table 6 as representative from different site. The table shows a more or less as the analysis is reliable and accurate. Generally out of 41 samples 36 samples have passed this check with most parameter while 5 samples pass the check with only some parameter.

4.8. Major Ions

4.8.1. Sodium and potassium (Na^+ & K^+)

Sodium is the second abundant cation in the subbasin Table 16. In the samples examined it ranges from 23 to 135mg/l. The mean is about 54.2mg/l. Most of the samples show a value ranging from 30 to 70mg/l. Sodium concentration shows in general an increasing tendency from the west escarpment towards the eastern tip of the study area. This is because of long time water-rock interactions. The main source of sodium in the study area could be sodium plagioclase (albite) and to some extent sodium may be retained by adsorption on mineral surface of lacustrine deposits having high cation exchange capacities such as clay before directly recharge to groundwater.

The minimum concentration of Na^+ with respect to K^+ is greater by 7mg/l in the groundwater sample. Potassium is lower than sodium in the area, because it is resistant to chemical attack while species containing sodium and calcium are more susceptible to weathering. The low concentration of potassium in general could be attributed to the lesser proportion of potassium feldspar.

4.8.2.Calcium and Magnesium

Calcium is the most abundant cations and magnesium takes the third order in the study area as per concentrations in milligram per litter. Because of their similar geochemical behavior calcium and magnesium are treated together. Most of the samples in the study area are sodium and calcium bicarbonate water types. Calcium ranges from 32mg/l to 78.3mg/l, higher concentrations are found at the centre and south west of the area. Magnesium ranges from 1.2mg/l to 36 mg/l. The main source of Calcium in the study area could be derived from weathering of calcic plagioclase and calcium rich pyroxene since there are no external factors (industries) which can be source of calcium in the area.

4.8.3. Chilorides

The mean concentration of chloride is 17 mg/l. It ranges from 0.15 mg/l to 69 mg/l. Only single BH with chloride of 85mg/l. Most of the samples are between 5.5 mg/l and 50 mg/l. The chloride concentration is high at plain areas as the general groundwater flow direction.

Table 16.Summary statistics of the groundwater sample result in the catchment

Constituent	Unit	Minimum	Maximum	Mean
EC	µS/cm	307	1038	554
TDS	mg/l	175	750	352
pH		7.09	8.30	7.60
Ca^{+2}	mg/l	34.2	79.3	57.4
Mg^{+2}	mg/l	1.20	36.0	17.0
Na^+	mg/l	23.0	135	54.2
K^+	mg/l	6.20	22	12.0
HCO_3^-	mg/l	126	468	360
NO_3^-	mg/l	0.00	17.5	5.20
Cl^-	mg/l	0.15	69	17.0
F^-	mg/l	0.00	2.2	0.84
SO_4^{-2}	mg/l	0.00	29.7	5.50
SAR	mg/l	0.73	6.8	1.90

4.8.4. Carbonets

Carbonate in the area is mainly in the form of bicarbonate. Bicarbonate is the major ion in the groundwater. The concentration of bicarbonate in boreholes ranges from 127 mg/l to 468 mg/l. The highest bicarbonate concentrations were detected in Modjo hand dug wells which have more than 461 mg/l of bicarbonate. The mean concentration for the boreholes is about 360 mg/l. Bicarbonate is by far the largest anion in the study area. All samples that show higher TDS with high concentration of HCO_3 and the lower TDS is the vice versa. Higher concentrations of HCO_3 are observed in wells located in the South east of the plain and a kind of decrease to the North and Western tip of the study area as shown on Figure 27 below.

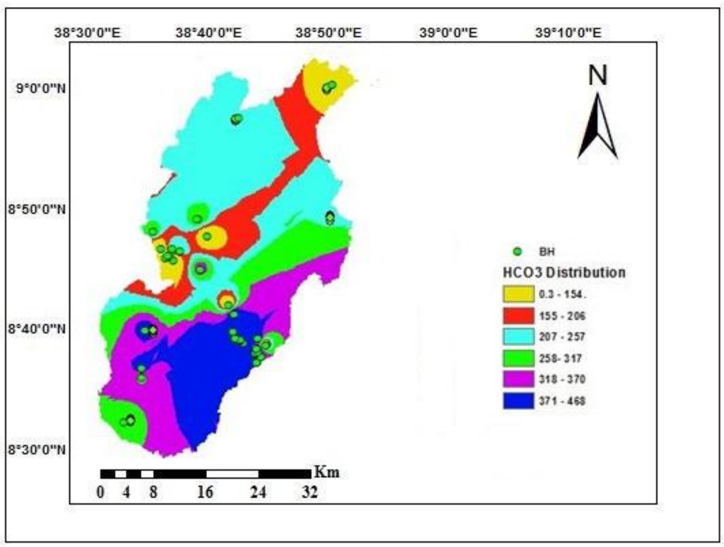


Figure 27. HCO_3 concentration distribution in groundwater of Modjo subbasin

4.9. Cluster Analysis

AquaChem 2012.5 software was used for groundwater cluster analysis in this study. Each cluster group is plotted on Piper graph and Box and Whisker summary plot (Figure 28), which shows the relative contribution of major cations and anions on a mill equivalent basis to the total ion content of the water. Calcium and sodium are the dominant cations in all water types. Calcium is the major cation, and bicarbonate is the dominant anion with a concentration of about 43% and 90% of the total cations and anions respectively. In this group, sulphate is found in very small amount which is about 2% of the total anions. This hydro-chemical cluster has typical characterized by its high TDS and EC values between 750ppm and 1038 µS/cm.

The spatial variation of Sulphat and chloride anions are very high where as calcium and bicarbonates are almost uniformly distributed in the basin.

Plotting of the chemical analysis of samples analyzed in the area using piper graph show that Ca - Na -HCO_3 water type in the recharge area, intermediate water type Ca-Mg-Na-HCO_3 in northern and central part of the subbasin and Ca-Mg-HCO_3 type towards the east and most of the water is clustered in the left part, suggesting that the water in the study area is a Calcium-Sodium-Magnesium-Bicarbonate type, which is characterized by a high concentration of HCO_3 and Ca whereas Na and Mg are available in minimum quantity.

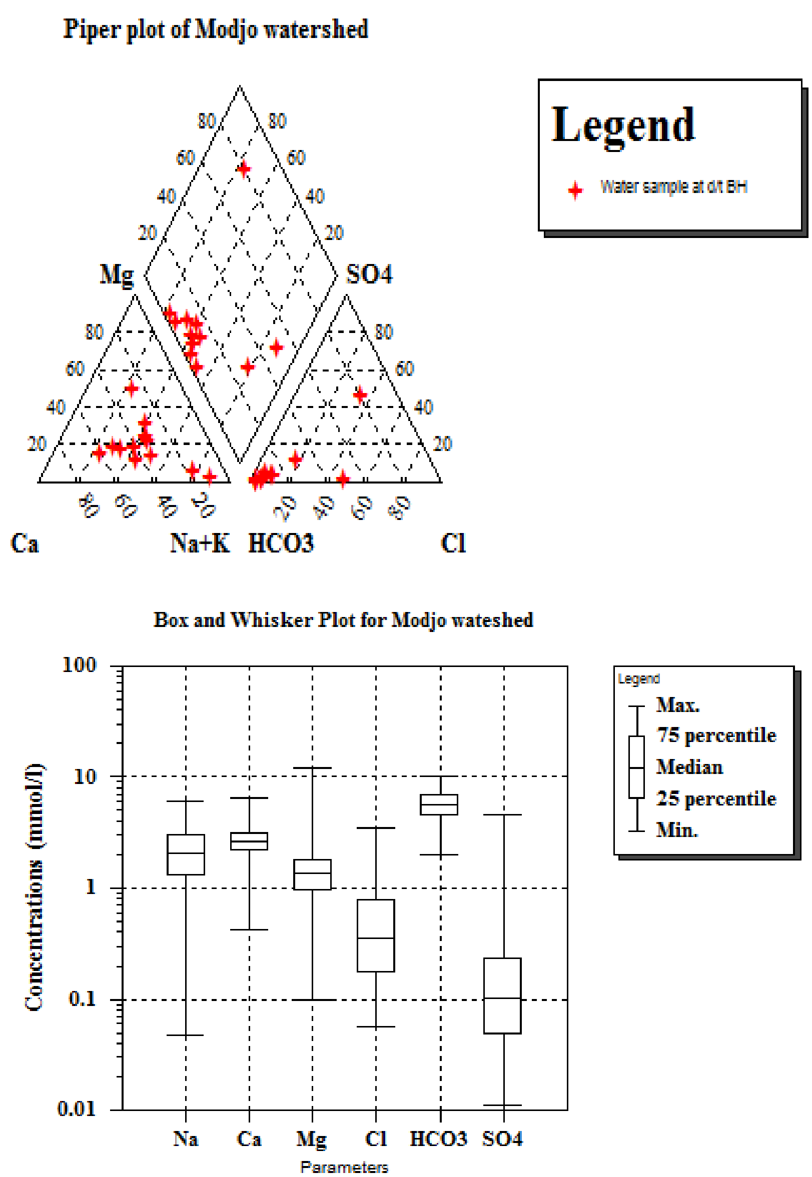


Figure 28. Clusters analysis of hydro-chemical and their statistical summary

4.10. Water Quality Evaluation for Irrigation

The water quality evaluation in this study was focus on the important parameters and criteria of the chemical water quality suggested for irrigation.

4.10.1. Salinity hazard

Based on EC as an index of salinity hazard suggested by (Bauder *et. al*., 2003), (Table 18), the water samples of the study area can be classified as good for irrigation Table 17.

Table 17.Suitability of groundwater in the study area for irrigation based on EC

Water samples	Ranges of EC (µS/cm)	Water class
All BH except BH-17	351- 763	Good
Only BH-17	1041	Medium/ permissible

Table 18.Suggested criteria for irrigation water use based upon conductivity

Classes of water	Electrical Conductivity (µS/cm)
Excellent	≤250
Good	250 – 750
Permissible1	750-2000
Doubtful2	2000-3000
UnsuiTable2	≥3000

(Sources: Bauder *et al*., 2003)

4.10.2. Sodcity hazard (SAR)

A soil permeability problem occurs with high sodium content in the irrigation water. The sodium hazard is typically expressed as the sodium adsorption ratio (SAR). This index quantifies the proportion of sodium (Na^{+}) to calcium (Ca^{++}) and magnesium (Mg^{++}) ions in a sample. The groundwater sample analysis shows that the groundwater of the study area is free of sodcity hazard based on SAR value as suggested by *(Bauder et. al., 2003)*, on table 20 below.

Table 19 Suitability of Groundwater of the study area for irrigation purpose based on SAR

Water samples	Range of SAR	Water class
All BH	0.07-0.68	Excellent

Table 20.General classification of water sodium hazard based on SAR values

SAR values Mg/l	Sodium hazard of water	Comments
1-9	Low	Use on sodium sensitive crops must be cautioned.
10-17	Medium	Amendments such as gypsum and leaching needed
18-25	High	Generally unsuitable for continues use
>26	Very High	Generally unsuitable for use

(Sources: Bauder *et al.*, 2003)

Wilcox plot on Figure 29 indicates the correlation of consantration analysis:-

i) All samples analysis result fall under S_1 curve of the plot indicating that the groundwater of the area is free of alkalinity (low sodium) hazards

ii) Most of the sample analysis result fall undercolomon C_2 of the plot suggesting that the groundwater consantration with medium salinity and some under C_3 shows high groundwater salinity is showen in some borehols.

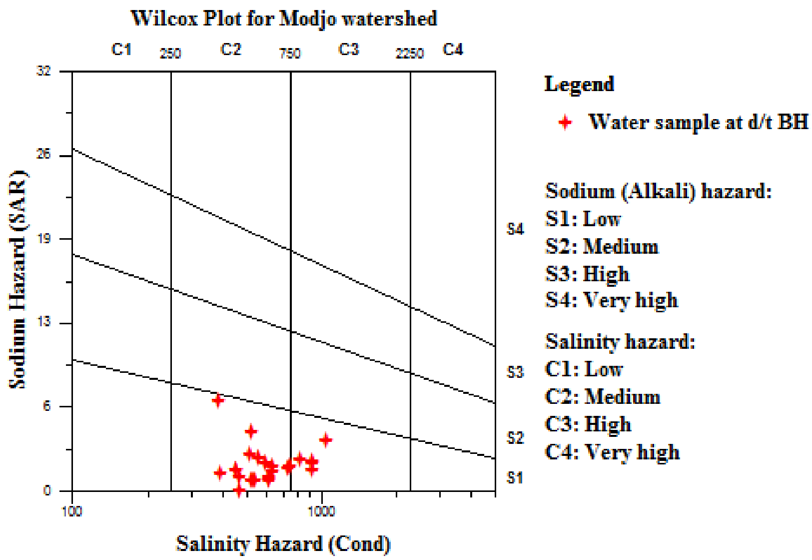


Figure 29. Degree of sodcity and salinity hazard in the groundwater of Modjo subbasin

4.10.3. Ionic balance

Harmful effects on soils appear when the ratio of Ca:Mg < 1. In this study the ratio of Ca to Mg in the groundwater was found to be 3.2 (Ca:Mg= 3.2); signifying that the groundwater is safe of this problems.

4.10.4. Toxicity problems

For toxicity problems the ions of primary concern are chloride, sodium and boron. Sometimes toxicity problems may occur even when these ions are in low concentrations. Sodium and chloride analysis in the sample shows below allowable limits to be toxic (i.e. the chloride concentration of the borehole samples in the study area except Kusaye-BH is suitable for irrigation). Analysis for boron was not done in this study but information data indicates that as no groundwater toxicity problems were recorded in the area since the groundwater has been used in some part of the subbasin for irrigation. Toxicity often accompanies and complicates a salinity or water infiltration problem; again there is no indication for these problems in sample analysis for salinity. From those justification, it is concluded that groundwater in the study area is free of toxicity problems or is suitable for irrigation from the point of toxicity.

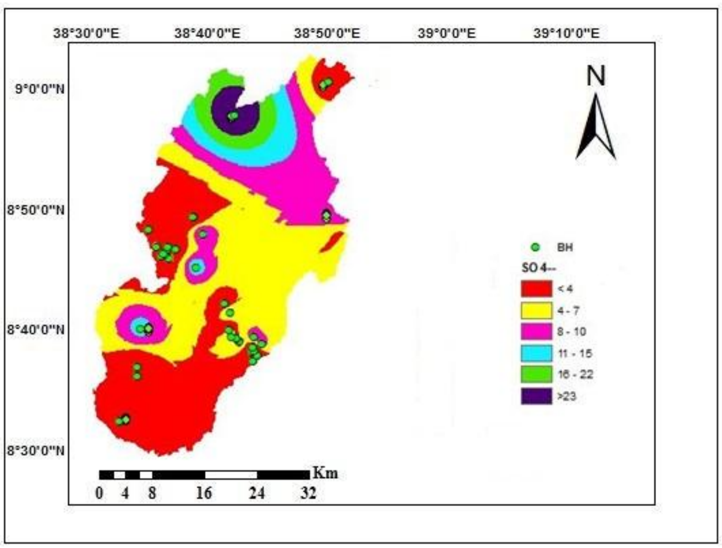


Figure 30 SO_4 concentration distribution in groundwater of Modjo subbasin

5. SUMMARY, CONCLUSION AND RECOMMENDATION

In Ethiopia the information gap in groundwater development and management is enormous; whereas knowledge of groundwater resource potential is important for groundwater management and sustainable use. Recharge is an important factor in evaluating groundwater resources but it is difficult to quantify. Hence estimation of groundwater recharge requires modeling of the interaction between all the important processes in the hydrological cycle (Jyrkama and Sykes, 2007).

In this study the long term seasonal groundwater recharge of Modjo river catchment (2,202 km^2) was estimated and the recharge zone is mapped through use of a grid based physically distributed model, WetSpass. The model applies up to date physical and empirical relationships of the subbasin for its efficiently running processes. Obviously, long term average hydro meteorological data and spatial patterns of watershed physical grid maps are used as main inputs for the model.

Seventeen model parameter variables are used as an input for the WetSpass model in ASCII grid map and dbase file formats. Season independent gridded base maps of soil, slope, and topography; and soil, land use and runoff coefficient parameters in dbase files are used in the model. Precipitation, potential evapotranspiration, temperature, wind speed and groundwater depth and land use map are also prepared and employed by the model, in ASCII grid format for both winter and summer seasons.

The model results show that all the water balance components are dependent on the soil type and land use classes. Thus, it can be noted that lack of relevant land use map in WetSpass groundwater recharge simulation leads to a wrong output, which could lead to wrong decisions. In this study, GIS and remote sensing techniques has been applied to develop the land use map of the basin and ERADAS IMAGINE 9.2 and ArcMap 10.2 has been used to process the satellite imagery obtain the accurate and up-to-date land use/ land cover map of the catchment.

Annual and seasonal values and ASCII grid map of runoff, evapotranspiration, interception, transpiration, soil evaporation and finally recharge of the subbasin are obtained as model output results.

The model results show that the mean annual recharge in the catchment is about 83 mm, which is about 8.9% of the mean annual precipitation. Thus an average of 183 Mm^3 of groundwater will be recharged per year or 5,802 l/s for 2,202km^2 area of Modjo river catchment.

The simulated mean annual surface runoff in the basin is 164 mm. Only about 17.6% of the mean annual runoff is contributed in winter season while the rest is contributed from the summer rainfall. In Ethiopian summer, rainfall is intensive and above the infiltration capacity of the soil hence a significant portion of the rainfall becomes runoff. Evapotranspiration is also high in summer, since most of the crops and vegetation actively grow in this season. The simulated mean annual evapotranspiration is about 686 mm/year which is equivalent to 73.5% of the long term mean annual precipitation of the basin. Analysis of the simulated results and correlating them with the general characteristics of the basin, shows that WetSpass is good enough to simulate the hydrological water balance components of the Modjo river basin provided that an accurate and up to date land use and soil maps are available.

It has also seen that the water balance components are dependent on the soil type and land use classes, thus high values of groundwater recharge are observed in the grassland land and agricultural land with silty loam and silty clay soils. This is due to good permeability of these soils and gentle topography. But all types of soils with tree and shrub and water body land-use areas have resulted low amounts of groundwater recharge. This is caused due to the release of higher amounts of transpiration through the plant and evaporation from the open water surface.

Also from recharge map it can be observed that more recharge at gentle slope and accumulated towards the lower elevation point of the watershed, this make ease of locating water abstraction point (site selection), on the other hand the surface runoff map can be used to identify part of the subbasin should gate more focus in soil and water conservation work. From geological map of the Ethiopian Rift (Kazmin, 1997) at a scale of 1: 25,000. The study area is mainly covered by 70% quaternary volcanic rock 30% unconsolidated sediment. According to (WSP, 2006) those rocks are highly fractured rocks and resulted a favorable situation for groundwater recharge and occurrence and are very important hydrological formation that are used as good source of groundwater in Ethiopia, hence in this catchment areas with more recharge implies more groundwater reserve.

The hydro-chemical analysis of water samples in the area revealed that the water samples from the north western highland escarpment have relatively lower values of TDS, EC, sodium and chloride. Generally, the ion concentrations increase when one is moving from the highland escarpment to the central part of the subbasin indicating the increased dissolution along the flow paths from recharge to discharge areas.

Plotting of the chemical analysis of samples collected in the area using piper graph show that most of the water is clustered in the left part, suggesting that the water in the study area is a Calcium-Sodium-Magnesium-Bicarbonate type, which is characterized by a high concentration of HCO3, Ca, Na and Mg.

In general, for most of the major constituents the samples show concentrations below the maximum allowable limits as indicated by different scholars and therefore the groundwater could be used safely for irrigation. Especially groundwater in Modjo subbasin is low in the sodium adsorption ratio (SAR) values making them favorable for all types of irrigation.

5.1. Recommendation

From the results of this study, the following recommendations are made:

- The water balance results obtained from this modeling can be used as base for future groundwater resources development and improvement of the catchment in particular, for soil and water conservation work in general.
- The largest amount of evapotranspiration simulated for the catchment, relative to the groundwater recharge and the surface runoff, indicates that much effort is needed to change the environmental conditions of the catchment by applying some soil and water conservation practices.
- An average 5,802 l/s recharge is calculated for the catchment, for further groundwater resource development plans of sustainable use, the abstraction rate both for irrigation and domestic water supply from the subbasin should be maintained under consideration of this rate.
- Well drilling requires huge amount of investment cost, however it is common to have problem in exploitation of groundwater in that unsuccessful rate of well production encounter, hence, using WetSpass output groundwater recharge map with consideration of geologic properties of the aquifer is recommended to reduce this problem in site selection for water abstraction point.
- The simulated annual surface runoff is 361Mm^3. Therefore, to harvest this excess water, it could be advantageous to practice flood control dams (artificial recharge). This is helpful in one way to reduce soil erosion and in the other way to enhance more recharge to groundwater.
- This study depends only on the hydro metrological data and special pattern of the subbasin to understand spatial and temporal groundwater recharge, further study should be investigated including aquifer property for more understanding of groundwater dynamics in the catchment for better groundwater resource development and management.
- The concentrations in the water sample shows below the maximum allowable limits and therefore the groundwater could be used safely for irrigation.

6. REFERENCES

Abrol I.P. S.P.Yadav and F. I. Massoud.1988. Salt Affected Soils and their management. FAO.Soils Bulletin 39: FAO, Rome

Adem G.and Batelaan O. 2006. Modeling Groundwater-Surface Water Interaction by coupling MODFLOW with WetSpa, Geophysical Research, Vol. 8, 03181

Ahmadi. Ziaei. N., Davary. K., Faridhosseini. A. & Izadi. A. and Rasoulzadeh. A. 2013. Estimation of groundwater recharge using various methods in Neishaboor Plain, Iran. Groundwater Modeling and Management under Uncertainty ISBN 978-1-138-00012-4

Alkuisi and A. El-Naqa. 2013. GIS based Spatial Groundwater Recharge estimation in the Jafr basin, Jordan – Application of WetSpass models for arid regions. Revista Mexicana de Ciencias Geológicas, v. 30, núm. 1, p. 96-109

Alvaro.2003.Physical Properties of Magnesium Affected Soils in Colombia. National University of Colombia, Palmira, Colombia. 6p

Al-Zu'bi. Al-zu'bi and N.A. al-Balqa. 2010. Estimation of Water Balance components in the Hasa basin with GIS based WetSpass Model. Jornal of Agronomy, volume 9, issue 3, pp. 119 -125.

Anderson.M.P.,and Woessner, W. W. 1992. Applied Groundwater Modeling. Acad Press, San Diego, USA

Ayenew Tenalem.1998.The hydrogeological system of the Lake District basin, Central Main Ethiopian Rift Published PhD thesis (ISBN.9061641586), Free University of Amsterdam, The Netherlands, 259pp

Ayers.R.S.and D.W. Westcot.1994. Water Quality for Agriculture. FAO Irrigation and Drainage Paper. 29 Rev.1. FAO, Rome, Italy. 201p.

Batelaan and F.De Smedt. 2001. WetSpass: a flexible GIS based distributed recharge methodology for regional groundwater modelling", Impact of Human Activity on Groundwater Dynamics, IAHS Publ. No. 269, pp. 11-17.

Batelaan.O.and F.De Smedt. 2007. GIS-based recharge estimation by coupling surface-subsurface water balances, Journal of Hydrology, 337, 337– 355.

Bauder,T.A.,R.M.Waskom and J.G. Davis. 2003. Irrigation water quality criteria. Colorado StateUniversityCooperativeExtension.http://www.ext.colostate.edu/pubs/crops/0050ml

Bauder. J.W. and T.A. Brock. 2001. Irrigation water quality, Soil amendment and crop effects on sodium leaching. Arid Land Research and Management.15: 101-113.

Behailu Berehanu. 2007. Impact of Industries and Urbanization on water Resource in Modjo River Catchment. Unpublished MSc Thesis, Addis Ababa university.

Benjamin N.N, Jacques M. and Jean S.R. 2007. Groundwater Recharge from Rainfall in the Southern Border of Lake Chadin Cameroon, World Applied Sciences Journal 2. Calmbach. L. 2003. Water Quality Data Analysis, Plotting, and Modeling. User's Manual (Ed.).Waterloo Hydrogeologic, Inc

Carter, T.R., M. Hulme, J.F.Crossley, S. Malyshev, M.G. New, M.E. Schlesinger, and H. Tuomenvirta. 2000. Climate Change in the 21st Century - Interim Characterizations based on the New IPCC Emissions Scenarios. The Finnish Environment 433, Finnish Environment Institute,Helsinki, 148 pp.

Chapman,T.1999. A comparison of algorithms for stream flow recession and baseflow separation. Hydrol. Processes13(5), 701–714

Clarke, R., Lawrence, A. and Foster, S. (1996). Groundwater: A threatened resource. Nairobi, Kenya: United Nations Environment Programme Environment Library No. 15.

Crosbie, R. Jolly, L., Leaney, F., Petheram, C & Wohling, D. 2010. Review of Australian groundwater recharge studies CSIRO: water for a healthy country National Research Flagship, 81p.

Cüneyt. Güler. Geoffrey D. Thyne, John E., McCray A. and Keith Turner. 2002. Evaluation of graphical and multivariate statistical methods for classification of water chemistry data. Hydrogeology Journal. 10:455–474

Dehayr. R., N. Diatloff and I. Gordon. 2006. Irrigation water quality salinity and soil structure stability. Queensland Government, NRM facts, Water Facts W 55, Brisbane Australia.4p.

Delleur Jacques. 1998. The Handbook of Groundwater Engineering, School of Civil Engineering Purdue University, West Lafayette, Indiana.

DeVries.J.J and Simmers I. 2002. Groundwater recharge: an overview of processes and challenges. Hydrogeol J 10(1):5–17

Dragoni.W. and Sukhija, B. S. 2013. Climate change and groundwater: a short review, p1-12, v.288; Special Publications, Geological Society, London, Dripps.W.R., Bradbury K. R. 2007. A simple daily soil-water balance model for estimating the spatial and temporal distribution of groundwater recharge in temperate humid areas. Hydrogeology Journal 15(3): 433–444.

Essington. M.E. 2004. Soil and Water Chemistry: An Integrative Approach. CRC Press, Boca

Fetter. C.W. 2001. Applied hydrology. Prentice-Hall, inc. upper Saddle River, NewJersey

Freeze, R.A. & Cherry, J.A. 1997. Groundwater. Prentice-Hall, Englewood Cliffs, N.J., USA. 604pp

Gebreryfael, H. 2008. Groundwater resource assessment through distributed steady-state flow modeling, Aynalem well field. Mekelle, Ethiopia. MSc Thesis, International Institute for Geo Information Science and Earth observation enschede, (unpublished).

Getachew Abrha. 2007. Groundwater Potential Assessment of Welenchiti Area. Unpublished MSc Thesis, Addis Ababa university.

Hem, J.D. 1985. Study and Interpretation of the Chemical Characters tics of natural Water. 3rd edition. U.S. Geological Survey, Alexandria, 263pp.

International Water Management Institute, Sri Lanka. 2012. groundwater availability and use in sub-saharan africa: PO box no. 2075, 127, Sunil Mawatha, Pelawatte, battaramulla, Sri Lanka http://www.iwmi.cgiar.org

Japanese International Cooperation Agency (JICA). 1990. Water resources study of the Jafr basin: Final Report, Amman, Jordan, pp 522.

Jyrkama, M.I., and Sykes, J.F. 2007. The impact of climate change on spatially varying groundwater recharge in the grand river subbasin (Ontario). Jour. Hydrology, 338(3-4): 237-250.

Kazmin V. and Seifemichael Berehe. 1978. Geology and development of the Nazret area Northern Ethiopia Rift. Note No. 100, EIGS.

Keren, R.2000. Salinity In: Sumner, M.E (eds.). Hand book of soil science.CRC press. pp.126.

Mehreteab Tesfai. V. Dawod and Kiflemariam Abreha. 2002. Management of salt affected soils in the NCEW ‘Shemshemia irrigation scheme in the Upper Gash Valley of Eritrea.

Ministry of Water Resources. 2001. Initial national communication of Ethiopia to the United Nations Framework Convention on Climate Change (UNFCCC). A report submitted to the conference of parties of the UNFCCC under the GEF support Climate Change Enabling Activities Project of Ethiopia. Ethiopia, Addis Ababa

Ministry of Water Resources. 2011. Ethiopia: Strategic Framework for Managed Groundwater Development

Nata T. 2006. Water balance of Hantebet basin *CIGAR E journal*

Nordstrom. D. 2004. Modeling Low-temperature geochemical processes. In: Treatise on Geochemistry. Holland, H., Turekian, K., (Eds). Volume 5, Surface and Ground Water,Weathering and Soils, Drever, J., (Ed.) 5.02, pp. 37-72. Elsevier Ltd.

Obuobie Emmanuel, B. Diekkrüger and B. Reichert. 2008. Estimation of groundwater recharge in the context of future climate change in the White Volta River Basin, West Africa. Dissertation, http://hss.ulb.uni-bonn.de/diss_online elektronischpubliziert.

Pressurized Irrigation Techniques book chapter -7. Water quality for irrigation. (n.d)

Raghunath H.M. 2006. Hydrology Principles, Analysis and Design: Revised edition. New Age International Publishers, New Delhi, India.

Richard H and McCuen. 1989. Hydrologic analyses and Design Englewood Cliffs. New Jersey.

Russell S. Crosbie and James L. McCallum & Glen R. Walker & Francis H. S. Chiew. 2010. Model ling climate-change impacts on groundwater recharge in the Murray-Darling Basin, Australia, Hydrogeology Journal, 18: 1639 –1656.

Scanlon B.R, Healy R.W, and Cook P.G. 2002. Choosing appropriate techniques for quantifying groundwater recharge. Hydrogeology Journal, 10:18–39. DOI 10.1007/s10040-0010176-2. http://dx.doi.org/10.1007/s10040-001-0176-2

Schlumberger Water Services. 2008.Water Quality Data Analysis, Plotting, and Modeling

Semu Moges. 2012. Agricultural Use of Ground Water in Ethiopia: Assessment of Potential and Analysis of Economics, Policies, Constraints and Opportunities, Addis Ababa University, Ethiopia September, 2012)

Shiklomanov, I. A. and Rodda, J. C. (2003). *World Water Resources at the Beginning of the Twenty-frst Century*. Cambridge: Cambridge University Press.

Sorooshian S and Hsu. K.L. 2008. Hydrological Modelling and the Water Cycle, Springer-Verlag

Subramanya, K. 2008. Engineering Hydrology 3rd edition, Tata McGraw Hill, New Delhi, India, 155 162

Szymczak, and K. Krężałek. 2010. Evaluation and verification of the WetSpa model based on selected rural catchments in Poland. Journal of Water and Land Development, No. 14, pp 115133

Teklebirhan Arefaine, Dessie Nedaw andTesfamichael Gebreyohannes.2012. Groundwater Recharge, Evapotranspiration and Surface Runoff Estimation Using WetSpass Modeling Method in Illala Catchment, Northern Ethiopia, Momona Ethiopian Journal of Science (MEJS)4(2): 96–110

Tesfamichael Gebreyohannes, De Smedt F., Miruts H., Solomon G., Kassa A., Kurkura K., Abdulwassie H., Bauer H., Nyssen J., Moeyersons J., Deckers J., Mitiku H. and Nurhussen T. 2010. Large scale geological mapping of the Geba basin, northern Ethiopia. Tigray Livelihood Paper No 9, VLIR – Mekelle University IUC Program, 46 pp. ISBN 978-90-8826-134-3.

Thornthwaite, C.W. 1948. An approach towards a rational classification of climate. Geog. Rev., 38, 55–94.

Thornthwaite, C.W. and J.R. Mather. 1955. *T*he Water Balance. Publications in Climatology. Drexel Institute of Technology, Centerton, New Jersey, Vol. VIII, No.1

Todd, D.K. 2005. Groundwater hydrology. Wiley, Hoboken, NJ, 636pp. Yazew E .2005. Development and management of irrigated lands in Tigray, Ethiopia. PhD thesis

UNESCO. 2001. IHP-V Technical Documents in Hydrology No. 39, Vol. 111, Paris.

Verstraeten W. W., Veroustraete F. and Feyen J. 2008. Review on Assessment of Evapotranspiration and Soil Moisture Content Across Different Scales of Observation, Sensors 2008, 8, 70-117

Wilcox. L. V. 1955. Classification and use of Irrigation Waters. U.S. Dept. Agric. Circ. 969, Washington, D.C., 19 p.

WSP.2006.Country Case-Study by theCost-Effective Boreholes Flagship of the Rural Water Supply NetworkFinal Report June 2006

Yair A., Kossovsky A. 2002. Climate and surface properties: hydrological response of small and semi-arid subbasins. Geomorphology 42(1–2): 43–57.

Yangxiao.Zhou.2017.Applied Groundwater Modelling:UNESCO-IHE Lecture Notes LN0113/09/1,Delfit.

Yibeltal Tafere. 2006. GIS and RS Assisted Water balance Computation of the Geba River Basin, Tigray, Ethiopia. MSc Thesis, The Netherlands (unpublished).

7. APPENDICES

Appedex Table 1.Mean monthly precipitation of all station (mm)

Month	Chefedonsa	D/zeyit	Modjo	Hombole	Koka	Ejere
Jan	16	12	13	12	6	13
Feb	30	24	30	16	18	21
Mar	50	45	46	23	40	47
Apr	58	61	56	48	59	53
May	48	49	55	57	63	61
June	131	92	96	108	70	66
July	296	230	248	140	222	287
Aug	322	271	229	188	225	296
Sep	148	108	110	128	98	101
Oct	21	26	28	34	28	37
Nov	4	6	6	10	10	12
Dec	8	5	2	6	6	7
Annual	1152	930	918	772	786	998
Summer	897	701	683	565	616	750
Winter	235	229	235	207	229	249

Appendix Table 2.Wind speed (m/s)

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Chefadonsa	2.4	2.6	2.5	2.5	2.6	2.4	2.1	2.0	2.0	2.5	2.6	2.4
D/zeyit	2.5	2.7	2.6	2.7	2.6	2.0	1.8	1.7	1.9	2.6	2.7	2.6
Modjo	2.3	2.2	2.3	2.5	2.5	2.4	2.3	2.0	1.9	2.4	2.5	2.4
Hombole	2.5	2.7	2.4	2.7	2.6	2.6	2.5	2.1	1.8	2.5	2.6	2.6
Koka	2.6	2.7	2.5	2.7	2.8	2.8	2.7	2.2	2.0	2.5	2.6	2.6
Ejere	2 .3	2.4	2.3	2.5	2.6	2.7	2.7	2.3	2.1	2.4	2.4	2.3

Appendix Table 3. Monthly mean temperature (^oC) for all station in and near the Modjocat chment

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Cef/donsa	14.8	15.9	16.9	17.5	17.9	17.0	16.4	17.1	15.8	14.5	14.1	13.9
Debrzeyit	16. 7	17.7	18.9	19.2	19.2	20.4	19.0	18.4	17.2	16.1	15.9	15.7
Modjo	17.9	18.0	19.2	19.5	20.1	22.8	21.2	20.7	20.4	16.6	16.1	15.9
Hombole	17.5	18.6	19.7	20.3	20.7	21.3	19.7	19.7	19.6	17.4	16.7	16.4
Koka	15.2	16.4	17.6	18.3	18.6	19.1	17.4	17.2	17.5	15.5	14.5	14.3
Ejere	17.3	18.4	19.9	20.6	21.6	23.5	22.2	21.9	21.1	17.8	17.2	16.2

Appedex Table 4.Mean summer, winter and annual temperature (˚C) for all station

S.No	Station	Elevation(m)	Winter	Summer	Annual
1	Chefedonsa	2400	16.0	17.3	16
2	Debrazeyit	1943	17.4	19.0	18
3	Modjo	1783	18.7	21.1	19
4	Hombole	1670	18.4	20.1	19
5	Koka	1597	16.3	17.9	17
6	Ejere	2233	19.0	22.2	20

Appedex Table 5. ETo (mm/day) for each station in and near the Modjo catchment

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Chefedonsa	4.8	5.4	5.7	5.9	6.0	5.8	5.2	5.1	5.2	5.4	5.1	4.8
D/zeyit	5.3	5.8	6.1	6.5	6.3	5.7	5.1	5.0	5.3	5.8	5.5	5.2
Modjo	5.2	5.7	6.0	6.5	6.5	6.4	6.0	5.7	5.7	5.8	5.5	5.1
Hombole	5.4	6.0	6.1	6.6	6.5	6.4	6.0	5.6	5.3	5.8	5.4	5.3
Koka	5.1	5.7	5.8	6.2	6.3	6.2	5.6	5.2	5.0	5.4	5.3	5.0
Ejere	4.9	5.2	6.0	6.5	6.7	6.9	6.7	6.2	6.0	5.7	5.3	4.9

Appendix Table 6.Chemical analysis reliability check

Shimbire meda Check	Attention Value	Analysis Value	Result
Balance (C-A)/(C+A)*100	<5%	-2.63	yes
TDS Entered/Conductivity	55< ## <75%	66	yes
K+/(Na+ + K+)	<20%	11	yes
Mg++/(Ca++ + Mg++)	<40%	20	yes
Ca++/(Ca++ + SO4--)	>50%	99	yes
Na+/(Na+ + Cl-)	>50%	89	yes
D/zeyit Air force	Attention Value	Analysis Value	Result
Balance (C-A)/(C+A)*100	<5%	-0.38	yes
TDS: (Entered - TDS180 calculated)/Entered*100	<5%	-2.75	yes
TDS Entered/Conductivity	55< ## <75%	62	yes
K+/(Na+ + K+)	<20%	11	yes
Mg++/(Ca++ + Mg++)	<40%	26	yes
Ca++/(Ca++ + SO4--)	>50%	93	yes
Na+/(Na+ + Cl-)	>50%	83	yes
Gafat #10	Attention Value	Analysis Value	Result
Balance (C-A)/(C+A)*100	<5%	-1.02	yes
TDS Entered/Conductivity	55< ## <75%	65	yes
K+/(Na+ + K+)	<20%	13	yes
Mg++/(Ca++ + Mg++)	<40%	31	yes
Ca++/(Ca++ + SO4--)	>50%	95	yes
Na+/(Na+ + Cl-)	>50%	86	yes
Roggee	Attention Value	Analysis Value	Result
Balance (C-A)/(C+A)*100	<5%	0.27	yes
TDS: (Entered - TDS180 calculated)/Entered*100	<5%	1.48	yes
TDS Entered/Conductivity	55< ## <75%	62	yes
K+/(Na+ + K+)	<20%	10	yes
Mg++/(Ca++ + Mg++)	<40%	39	yes
Ca++/(Ca++ + SO4--)	>50%	90	yes
Na+/(Na+ + Cl-)	>50%	78	yes
Haroressa	Attention Value	Analysis Value	Result
Balance (C-A)/(C+A)*100	<5%	-2.35	yes
K+/(Na+ + K+)	<20%	10	yes
Mg++/(Ca++ + Mg++)	<40%	28	yes
Tedecha	Attention Value	Analysis Value	Result
Balance (C-A)/(C+A)*100	<5%	-2.63	yes
TDS Entered/Conductivity	55< ## <75%	66	yes
K+/(Na+ + K+)	<20%	11	yes
Mg++/(Ca++ + Mg++)	<40%	20	yes
Ca++/(Ca++ + SO4--)	>50%	99	yes
Na+/(Na+ + Cl-)	>50%	89	yes
Galaye	Attention Value	Analysis Value	Result
Balance (C-A)/(C+A)*100	<5%	0.1	yes
TDS: (Entered - TDS180 calculated)/Entered*100	<5%	1.13	yes

TDS Entered/Conductivity	55< ## <75%	56	yes
K+/(Na+ + K+)	<20%	14	yes
Mg++/(Ca++ + Mg++)	<40%	42	no
Ca++/(Ca++ + SO4--)	>50%	96	yes
Na+/(Na+ + Cl-)	>50%	87	yes
Modjo #3	Attention Value	Analysis Value	Result
Balance (C-A)/(C+A)*100	<5%	-2.77	yes
TDS Entered/Conductivity	55< ## <75%	66	yes
K+/(Na+ + K+)	<20%	10	yes
Mg++/(Ca++ + Mg++)	<40%	20	yes
Ca++/(Ca++ + SO4--)	>50%	99	yes
Na+/(Na+ + Cl-)	>50%	95	yes
Modjo #1	Attention Value	Analysis Value	Result
Balance (C-A)/(C+A)*100	<5%	0.24	yes
TDS Entered/Conductivity	55< ## <75%	55	yes
Conductivity/sum MEQ Cations	90< ## <110%	6148	no
K+/(Na+ + K+)	<20%	10	yes
Mg++/(Ca++ + Mg++)	<40%	28	yes
Na+/(Na+ + Cl-)	>50%	88	yes
Modjo hund dug	Attention Value	Analysis Value	Result
Balance (C-A)/(C+A)*100	<5%	-6.08	no
TDS Entered/Conductivity	55< ## <75%	65	yes
K+/(Na+ + K+)	<20%	10	yes
Mg++/(Ca++ + Mg++)	<40%	35	yes
Ca++/(Ca++ + SO4--)	>50%	96	yes
K+/(Na+ + K+)	<20%	13	yes
Mg++/(Ca++ + Mg++)	<40%	19	yes
Ca++/(Ca++ + SO4--)	>50%	87	yes
Na+/(Na+ + Cl-)	>50%	64	yes

Appendix Table 7.Water sample collected and anal sized for its chemical concentration

Local Name	X	Y	Elv	Well depth(m)	EC (µs/cm)	TDS(ppm)	Water T ^{O}c	pH
Ziquala/Adulala	489485	943724	1724	140	486	310	21	7.53
Modjo Abudab	512159	946729	1770	180	392	196	19	7.25
Galiyee	485970	935007	1708	98	453	253	42	7.49
Kusaye	498233	939885	1646	88	1621	1036	21	8.02
Modjo Lume #3	512957	947774	1771	134	519	376	21	7.35
Modjo #4	511927	948292	1761	113	517	360	21	7.90
Modjo #3	512408	948682	1773	80	590	390	21	7.25
Modjo#1	512011	949196	1766	80	599	449	21	8.30
Modjo Nylone	513773	949998	1787	148	502	344	20	8.32
Gafat #7	509385	950325	1793	150	915	450	21	7.90
Gafat #8	509020	950736	1796	150	915	400	21	8.00
Gafat #9	508684	951058	1802	146	915	600	21	7.60
Modjo Dairy De	512282	951356	1773	150	700	650	22	7.60
Modjo 1(towen)	512282	951356	1773	123	600	300	22	6.88
Gafat #1	507491	952694	1827	102	950	630	21	7.70
Gafat #10	507950	951364	1816	150	741	482	21	7.15
Mo/Biyo hand/d	507714	955875	1849	33	728	476	21	7.44
D/Z-Air force	500909	964676	1886	36	628	391	21	7.48
D/Z-Blue Nile plastic	495765	966397	1906	60	614	375	21	7.69
D/Z-Sahilu	494829	967088	1917	80	538	349	21	7.71
D/Z-Elfora Agro-industry	494145	966864	1939	102	480	196	19	7.38
D/Z Genesis farm #1	495447	968068	1913	70	469	286	21	7.57
D/Z-Green star	494598	967157	1927	80	307	175	22	8.05
D/Z -Health college	497100	968198	1896	92	453	306	21	7.49
D/Z-Veternary collage BH	500078	968505	1889	74	1041	635	21	7.87
Shimbire meda	500494	974376	1896	80	530	350	22	7.09
Shimbire meda	500424	974376	1894	80	615	397	21	8.30
D/Z-Girma G/Kidan	495561	968574	1906	60	464	303	21	7.21
D/Z-Oxford	493179	968613	1912	108	605	290	19	7.50

D/Z-Hora Tannery	498633	970028	1889	74	607	300	20	7.40
D/Z- Dugda PLC	502364	970907	1885	74	592	285	20	7.04
Manginso	508639	993924	2481	132	524	344	21	7.42
Beike-Areda Goro	527037	100020	2488	180	388	350	21	7.40
Tedecha	491648	971873	1925	140	615	220	21	8.00
Roge	490198	952922	1791	135	632	393	21	7.80
Haroresa	489373	945542	1731	90	553	750	21	7.80
Liben Gardula	496234	939700	1659	12	1621	1036	21	8.02
APW-039-10E	507157	977107	2005	160	1528	1030	21	6.78
Ude Village	506490	957774	1791	155	721	454	21	7.24
Beike-Areda Goro2	535170	100729	2488	180	388	350	21	7.40
Galiyee2	477054	924477	1708	98	453	253	42	7.49

Local Name	NO2- (mg/l)	NO3- (mg/l)	F-(mg/l)	HCO3-(mg/l)	CO3-- (mg/l)	SO4--(mg/l)	PO4---(mg/l)	Hard ness
Ziquala -Adulala	0.00	7.50	2.20	297.2	0.00	3.96	0.33	155
Modjo Abudab stab	0.00	0.88	1.33	439.2	0.00	0.00	0.01	150
Galiyee	0.00	10.0	0.00	271.3	0.00	3.03	0.22	138
Kusaye	0.00	0.42	4.40	801.4	0.00	37.8	0.62	114
Modjo Lume #3	0.00	10.5	1.40	333.1	0.00	3.96	0.21	177
Modjo #4	0.00	7.30	0.40	439.2	0.00	0.00	0.00	200
Modjo #3	0.00	3.30	1.10	381.7	0.00	1.06	0.39	188
Modjo#1	0.01	0.89	0.82	341.6	18.0	0.00	0.00	160
Modjo Ethiojapan Nylon	0.00	0.00	1.47	362.1	0.00	10.0	0.00	160
Gafat #7	0.01	1.60	0.90	427.2	0.00	14.0	0.00	130
Gafat #8	0.01	2.50	1.10	463.6	0.00	0.00	0.00	165
Gafat #9	0.03	9.20	0.90	427.0	0.00	0.00	0.00	138
Modjo Dairy Development	0.01	6.00	0.52	268.4	0.00	0.00	0.05	148
Modjo Lume #1(towen)	0.00	7.92	1.26	464.8	26.4	10.0	0.28	145
Gafat #1	0.18	2.70	1.50	414.8	0.00	0.00	0.00	192
Gafat #10	0.00	10.5	1.90	468.8	0.00	8.98	0.04	264
Modjo-Biyo hand dug	0.00	10.0	0.45	461.2	0.00	7.39	0.28	284
D/Z-Air force	0.00	17.5	0.45	379.2	0.00	13.7	0.64	239

D/Z-Blue Nile plastic	0.00	5.00	0.62	300.0	0.00	7.00	0.30	256
D/Z-Elfora Agro-industry	0.03	6.70	0.70	208.0	0.00	0.78	0.24	220
D/Z Genesis farm #1	0.00	0.03	0.57	306.0	0.00	0.60	0.10	127
D/Z-Green star	0.00	0.06	0.15	181.7	0.00	0.55	0.10	125
D/Z -Health college	0.00	10.0	0.20	271.3	0.00	3.03	0.22	138
D/Z-Veternary collage BH	0.00	0.44	0.72	625.0	0.00	6.00	0.20	145
Shimbire meda	0.00	13.5	0.00	348.4	0.00	2.11	0.33	244
Shimbire meda	0.05	1.90	0.50	256.2	18.0	1.50	0.10	183
D/Z-Girma G/Kidan	0.00	0.00	0.30	319.6	0.00	0.53	0.33	189
D/Z-Oxford	0.01	3.20	1.40	265.0	0.00	5.80	0.37	250
D/Z-Hora Tannery	0.00	6.70	0.68	380.6	0.00	9.00	0.10	268
D/Z- Dugda PLC	0.00	2.05	0.82	236.0	0.00	11.0	0.12	232
Manginso	1.01	1.00	1.72	225.5	0.00	29.7	0.02	233
Beike-Areda Goro	0.00	2.00	1.30	125.7	0.00	3.00	0.24	225
Tedecha	0.02	1.20	0.40	341.6	0.00	0.00	0.10	213
Roge	0.01	8.90	0.80	402.6	0.00	12.0	0.50	232
Haroresa	0.01	2.50	0.89	409.0	0.00	0.00	0.23	169
Liben Gardula	0.00	0.42	4.40	801.4	0.00	37.8	0.62	106
APW-039-10E	0.51	0.02	0.81	10.00	0.00	0.00	0.64	123
Ude Village	0.29	0.00	0.63	6.200	0.06	0.00	0.31	108
Beike-Areda Goro2	0.00	0.00	1.30	125.6	0.00	3.00	0.24	203
Galiyee2	0.00	10.0	0.00	271.3	0.00	3.03	0.22	138

Location Name	NH4 (mg/l)	Na+ (mg/l)	K+ (mg/)	Ca+(mg/l)	Mg+ (mg/l)	Fe (mg/l)	Mn++ (mg/l)	Cl (mg/l)
Ziquala -Adulala	0.11	48.5	7.60	55.2	4.30	0.00	0.00	6.70
Modjo Abudab stab	0.00	62.0	10.0	44.0	9.60	0.00	0.00	12.0
Galiyee	0.25	42.0	11.5	32.2	14.3	0.00	0.00	9.60
Kusaye	0.11	345	20.0	20.9	11.1	0.02	0.00	85.4
Modjo Lume #3	0.05	52.0	12.8	52.5	11.3	0.00	0.00	5.80
Modjo #4	0.06	91.8	11.0	57.7	13.6	0.08	0.00	25.5
Modjo #3	0.06	65.0	12.0	60.5	9.20	0.00	0.02	5.80
Modjo#1	0.00	69.7	13.2	47.0	11.0	0.00	0.00	14.2
Modjo Ethiojapan Nylon	0.00	70.0	15.0	52.0	9.00	0.00	0.00	5.00

Gafat #7	0.00	74.8	17.2	52.1	21.9	0.15	0.00	26.6
Gafat #8	0.04	71.4	13.9	59.3	18.5	0.00	0.00	20.8
Gafat #9	0.00	61.2	12.5	74.1	18.2	0.04	0.00	35.5
Modjo Dairy Development	0.00	74.8	8.30	25.7	4.00	0.00	0.00	28.4
Modjo Lume #1(towen)	0.00	70.0	10.5	53.6	2.64	0.00	0.10	8.00
Gafat #1	0.13	57.8	10.3	65.7	17.8	0.00	0.00	28.4
Gafat #10	0.25	70.0	17.5	73.0	20.0	0.02	0.00	18.2
Modjo-Biyo hand dug	0.15	66.0	12.40	73.9	24.3	0.02	0.00	15.4
D/Z-Air force	0.14	50.0	10.20	71.2	15.1	0.00	0.00	15.4
D/Z-Blue Nile plastic	0.15	34.0	9.00	44.0	36.0	0.00	0.00	7.00
D/Z-Sahilu	0.10	30.0	8.10	54.4	21.9	0.00	0.00	0.00
D/Z-Elfora Agro-industry	0.12	2.20	3.70	50.0	22.8	0.01	0.01	2.00
D/Z Genesis farm #1	0.11	23.0	6.20	52.0	24.0	0.00	0.00	8.00
D/Z-Green star	0.11	19.0	1.20	43.5	4.34	0.00	0.02	0.20
D/Z -Health college	0.25	42.0	11.5	32.2	14.3	0.00	0.00	9.60
D/Z-Veternary collage BH	0.25	138.	12.0	36.0	36.0	0.00	0.00	0.00
Shimbire meda	0.11	31.0	6.80	78.3	11.9	0.00	0.00	5.80
Shimbire meda	0.00	33.0	9.00	48.0	15.3	0.03	0.00	17.7
D/Z-Girma G/Kidan	0.25	25.0	7.30	43.2	19.8	0.00	0.00	8.00
D/Z-Oxford	0.23	74.0	6.90	48.0	20.0	0.04	0.02	7.50
D/Z-Hora Tannery	0.15	57.8	5.60	43.3	26.3	0.14	0.00	12.8
D/Z- Dugda PLC	0.19	74.0	11.0	44.0	26.0	0.00	0.04	9.00
Manginso	0.39	77.0	22.0	16.6	3.24	0.27	0.00	32.8
Beike-Areda Goro	0.27	80.0	20.0	8.40	1.20	0.20	0.00	69.0
Tedecha	0.00	28.6	8.90	57.3	18.7	0.00	0.00	10.6
Roge	0.10	64.6	11.9	44.9	29.2	0.00	0.00	28.4
Haroresa	0.16	76.5	14.9	49.0	11.4	0.02	0.20	12.4
Liben Gardula	0.11	345	20.0	20.9	11.1	0.02	0.00	85.5
APW-039-10E	0.20	208	32.5	174.8	4.9	0.10	0.00	28.4
Ude Village	0.19	52.0	15.0	64.0	24.5	0.02	0.00	22.7
Beike-Areda Goro2	0.27	80.0	20.0	8.4	1.2	0.20	0.00	69.0

Appedix Table 8.Water level and water yield (l/s) of different BH

Site Name	Water level (m)	Yield(l/s)	Site Name	Water Level	Yield(l/s)	Site Name	Water Level	Yield(l/s)
Hombole,	25	2.5	Chefa donsa Town	40	2.7	Koka 2 Wonji	19	2.0
Air Force Base 1 D/Z	35	3.6	Chefadonsa 1	60	6.6	Koka Alem Tena	12	1.9
Debre Zeit United Om	29	3.0	Chefadonsa M	46	4.7	Koka 3 Wonji	15	1.8
Debre Zeit Vet Lab 12	24	2.5	Modjo Market1	22	3.3	Debrezeit 3a D/Z	56	3.6
Debrezeit (Farm) 3	20	2.5	Modjo Market3	58	5.8	D/Z Air Force	35	2.7
Debrezeit 2	8	1.8	Modjo market 2	37	5.3	Ejere1	68	3.0
Debrezeit 2a	45	3.5	Zuquala 2 Ombole	29	1.7	Ejere2	120	4.3

Appedex Table 9.Average Agro-metrological data of the catchment from all station

Stations	Elevation (masl)	Average Precipitation (mm)			Average PET (mm)			Average daily temperature (°C)			Average wind speed (m/s)			Average Gwdepth (m)
		winter	summer	annual	winter	summer	annual	winter	summer	annual	winter	summer	annual	Gwd
Chefedonsa	2400	235	897	1152	1312	649	1961	16.0	17.3	16	2.52	2.11	2.4	40
D/zeyit	1943	229	701	930	1412	643	2055	17.4	19.0	18	2.62	1.84	2.3	35
Modjo	1783	235	683	918	1402	723	2125	18.7	21.1	19	2.41	2.16	2.4	33
Ombole	1670	207	565	772	1435	710	2145	18.4	20.1	19	2.58	2.26	2.5	27
Koka	1597	229	616	786	1359	672	2031	16.3	17.9	17	2.62	2.4	2.6	15
Ejere	2233	249	750	998	1391	781	2172	19.0	22.2	20	2.68	2.6	3.2	96

Appedex Table 10.Soil parameter table for Modjo subbasin

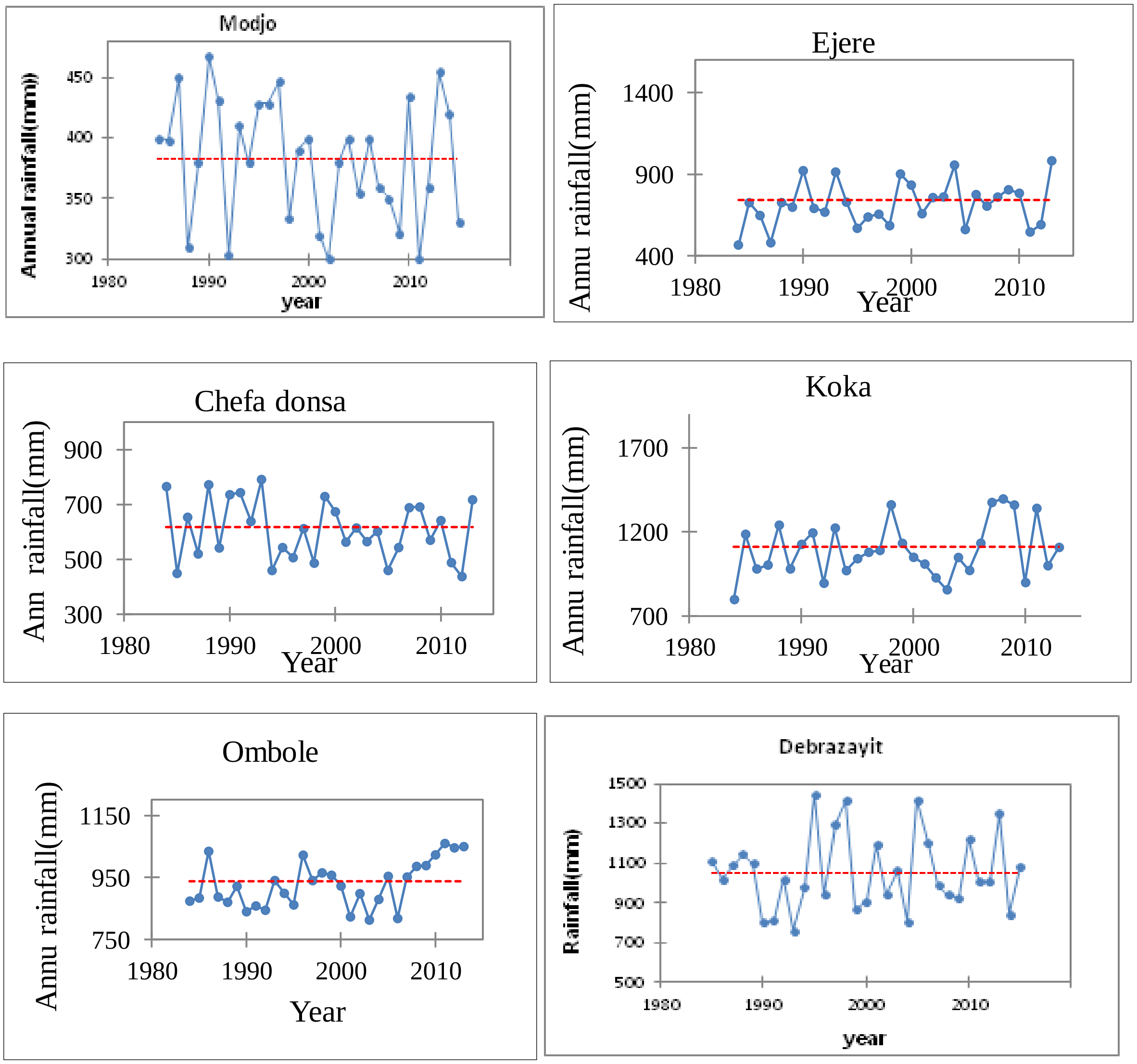
Code	SOIL	FIED CAPA	WILTIG PNT	PAW	RESIDU AL WC	A1	EVAPO DEPTH	TENSIO NHH	P_FRAC _SU	P_FAC_ W	Teta
12	clay	0.46	0.33	0.13	0.09	0.21	0.05	0.37	0.95	0.85	0.852
5	loam	0.25	0.12	0.13	0.027	0.37	0.05	0.11	0.15	0.02	0.333
11	silty clay	0.43	0.27	0.16	0.056	0.23	0.05	0.34	0.84	0.75	0.754
4	Silty loam	0.29	0.1	0.19	0.015	0.4	0.05	0.21	0.26	0.07	0.408

Appendix Table 11. Mean monthly relative humidity (%) in all station

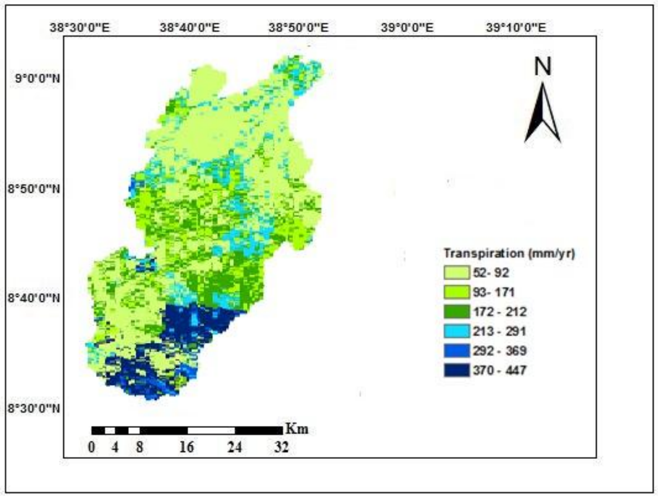
Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Chefedonsa	0.545	0.463	0.602	0.665	0.664	0.695	0.896	0.914	0.811	0.688	0.679	0.551
Debrazeyit	0.532	0.449	0.556	0.610	0.598	0.631	0.799	0.802	0.722	0.665	0.670	0.543
Modjo	0.482	0.405	0.506	0.567	0.548	0.561	0.715	0.710	0.644	0.602	0.613	0.492
Hombole	0.433	0.350	0.459	0.554	0.509	0.537	0.662	0.632	0.577	0.583	0.593	0.468
Koka	0.442	0.537	0.498	0.621	0.597	0.581	0.724	0.719	0.642	0.630	0.630	0.487
Ejere	0.467	0.389	0.485	0.552	0.521	0.498	0.624	0.622	0.579	0.552	0.579	0.484

Appendix Table 12. Mean monthly solar radiation ($MJ/m^2/day$) in all station

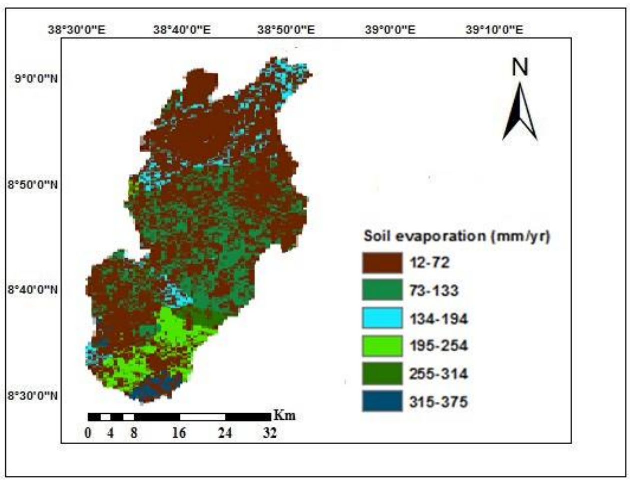
Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Chefedonsa	25.08	27.87	25.44	23.91	23.50	21.32	15.27	15.51	25.53	24.85	24.33	24.24
D/zeyit	26.24	28.62	27.35	27.52	26.75	26.32	20.96	23.58	28.25	26.35	25.05	25.28
Modjo	26.02	28.56	28.78	28.81	27.69	27.32	24.09	25.91	28.71	26.39	25.05	25.42
Hombole	25.88	28.42	28.77	28.62	27.43	27.85	24.88	27.07	28.29	26.12	24.61	25.34
Koka	24.79	28.31	25.29	25.39	22.96	25.28	19.32	19.13	25.34	21.01	21.62	24.47
Ejere	25.59	28.26	28.82	28.89	27.69	27.83	25.73	27.33	28.99	26.33	24.53	25.07



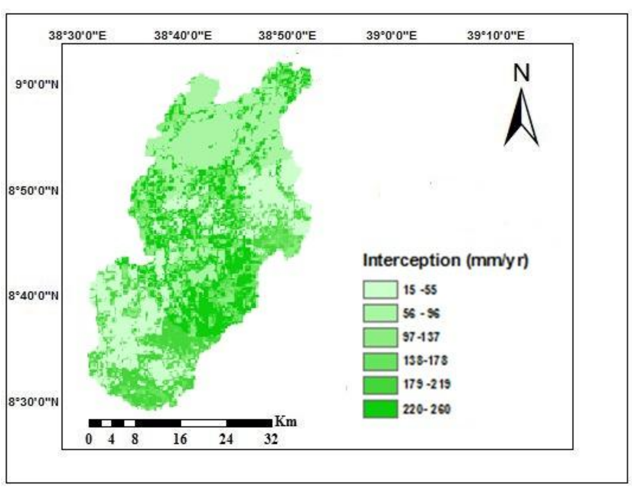
Appendix Figure 1. Homogeneity test for areal rainfall stations



Appendix Figure 2 Simulated annual transpiration with WetSpass model for Modjo subbasin



Appendix Figure 3 Simulated annual soil evaporation with WetSpass model for Modjo subbasin



Appendix Figure 4 Simulated annual interception with WetSpass model for Modjo subbasin