ESTIMATION OF SPATIAL DISTRIBUTION OF GROUNDWATER RECHARGE AND CROPWATER REQUIREMENT OF POTATO IN HOLETTA WATERSHED, UPPER AWASH RIVER BASIN, ETHIOPIA

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ESTIMATION OF SPATIAL DISTRIBUTION OF GROUNDWATER RECHARGE AND CROPWATER REQUIREMENT OF POTATO IN HOLETTA WATERSHED, UPPER AWASH RIVER BASIN, ETHIOPIA

A Thesis Submitted to the Postgraduate Program Directorate through
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In Partial Fulfillments of the Requirement for the Degree of
MASTER OF SCIENCE IN IRRIGATION ENGINEERING

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HARAMAYA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

I hereby certify that I have read and evaluate this Thesis prepared under my guidance, by Deressa Workineh Nasho entitled '**Estimation of Spatial Distribution of Groundwater Recharge and Crop water Requirement of Potato in Holetta Watershed, Upper Awash River Basin, Ethiopia**''. I recommended that it be submitted as fulfilling the Thesis requirement.

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This Thesis is dedicated to my parents, for their never-ending love, support and encouragement.

STATEMENT OF THE AUTHOR

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ABBREVIATIONS AND ACRONYMS

ASTER	Advanced Space borne Thermal Emission and Reflection Radiometer
BCM	Billion cubic meter
CWR	Crop water requirement
DEM	Digital Elevation Model
ET	Evapotranspiration
ETo	Reference Evapotranspiration
FAO	Food and Agriculture Organization
GCP	Ground control points
GIS	Geographic Information System
GPS	Global Positioning System
ha	Hectare
HARC	Holetta Agricultural Research Center
HBRC	Holetta Bee Research Center
IR	Irrigation Requirement
ITCZ	Inter Tropical Convergence Zone
IWMI	International Water Management Institute
Kc	Crop coefficient
KPa	Kilo Pascal
L	Liter
m.a.s.l	Meter above sea level
MCM	Million cubic meters
mm	Mille meter
Mm^3	Million meter cubic
MoWIE	Ministry of Water Irrigation and Electricity
MoWR	Ministry of Water Resources
MPIM	Max-Planck Institute for Meteorology
NMA	National Meteorological Agency
PTE	Potential Evapotranspiration
R^2	Coefficient of Determination
RH	Relative Humidity
SRTM	Shuttle Radar Topographic Mission

UNFCCC	United Nations Framework Convention on Climate Change
UTM	Universal Transverse Mercator
WetSpa	Water and Energy Transfer between Soil Plant and Atmosphere
WetSpass	Water and Energy Transfer between Soil, Plants and Atmosphere under quasi-Steady
WMO	World Meteorological Organization
WWAO	Wolmera Woreda Agricultural Office

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ABSTRACT

Sustainable groundwater management requires knowledge of recharge. Recharge is also an important parameter in groundwater flow and transport models. Spatial variation in recharge due to distributed land-use, soil texture, topography, groundwater level, and hydrometeorological conditions should be accounted for in recharge estimation. Estimation of temporal and spatial distribution of recharge is a key factor for a long-term water resource planning. Therefore, this study strives to estimate spatial ground water recharge and crop water requirement of potato in holetta watershed, upper Awash River basin, Ethiopia. ***.*** *In this study the long term seasonal and annual groundwater recharge of Holetta Watershed (415.7 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 10.4 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. Also, 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. From the result, it is found that the long-term temporal and spatial average annual rainfall of 1,035mm was distributed as: surface runoff of 157 mm (15.1%), evapotranspiration of 770 mm (74.3%), and recharge of 109.45 mm (10.6%). Thus, an average of 45.5Mm^3 of groundwater recharged per year was estimated from the total watershed area. Reference evapotranspiration, effective rainfall, crop pattern data, and soil data are required to run the CROPWAT model. After all, data is analyzed the crop water requirement of potato (Solamum tuberosum L.) was calculated. The crop water requirement and irrigation requirement of potato crop was vary from month to month in this watershed. The monthly crop water requirements are 42.3, 94.8, 170.3, 141.8 and 33.8mm for Jan, Feb, Mar, Apr and May respectively. The monthly irrigation requirements are 42.3, 94.7, 161.8, 127.2 and 25mm for Jan, Feb, Mar, Apr and May respectively. The total crop water requirements and irrigation requirements are 483 mm/crop season and 451 mm/season respectively. Therefore, the volume surface water recharges in this watershed was satisfactory for irrigation requirements of potato crop in this watershed.*

Key words: Holetta Watershed, WetSpass model, groundwater recharge, CropWat model.

1. INTRODUCTION

Water is a primary source of life and is required in sufficient quantity and acceptable quality to sustain all human activities such as domestic needs, agriculture, industries, etc. This requirement, however, is hardly fulfilled in arid and semi-arid environments where water is a scarce resource (Hanjra and Qureshi, 2010). Past and recent studies have shown that the most suitable solution to this problem is the rational utilization of surface water (Vreke, 1994; Awulachew *et al*., 2007; Fenta *et al.,* 2015). Nonetheless, surface water is not a reliable source as it is prone to seasonal fluctuations and susceptible to contamination through anthropogenic activities such as point, non-point pollution sources and biological pollutions (Fenta *et al.,* 2015). However, groundwater is more suitable in quantity, readily available and is naturally protected from direct contamination by surface anthropogenic activities (Fenta *et al.,* 2015). It is the largest reservoir of liquid freshwater on the planet and is critical for sustaining life on earth, as it is used to satisfy different human and environmental needs (Zomlot *et al.,* 2015). Thus, this shows due emphasis should be given for development of groundwater resources.

In Ethiopia, groundwater is so far used mainly for drinking water supply, but there are developments in many parts of the country to carry out groundwater based irrigation from shallow and deep aquifers. Although several areas with very shallow aquifers have recently been developed for agriculture by farmers and private initiatives, the level of groundwater use is still very low. On the other hand, it is well understood that groundwater is of principal importance for Ethiopia to supplement the available surface water resources in providing drinking water to its population and for economic development (agriculture, livestock, industry, tourism) and in general to mitigate the effects of climate variability (Belete *et al.* ,2014).

The total groundwater storage potential in Ethiopia was estimated to be 12-30 billion cubic meter (Belete *et al.* 2014). It is lower when compared to the surface water potential 124.4 billion cubic meter (MOWE, 2013). However, this water potential has threatened by the impact of climate change. Different authors (Soliman, 2009; Melesse, 2011) indicated that climate change in the Upper Blue Nile basin of Ethiopia would occur and would shift and reshape the annual and seasonal climate patterns and variation in rainfall, reduced reservoir yield and erratic rainfall. In the same way, Asfaw (2013) indicated that an increasing trend of annual maximum temperature and annual future rainfall with seasonal variations was observed in Baro-Akobo Basin, Nile Basin. Variations in frequency; distribution and intensity of rainfall are now a common phenomenon in the country.

Research on water resource, in the past mostly focused on surface water and very little is known about the effect of climate change on groundwater. The impact of climate change on groundwater can be far-reaching and thus need to be investigated. Sustainable and efficient exploitation of the water resource to keep sustain the human race and other living things accurately quantification of this vital resource, water, spatially and temporally is the agenda of the day (Demissie *et al.*, 2013).

The Holetta watershed, which is located in the upper part of Awash River basin of Ethiopia. It is characterized by high population growth, existence of different national and regional research centers and irrigation projects and also expansion of urbanization. Due to all of those projects the surface water cannot fulfill the water demands of the society for different use. Especially the water demand for irrigation and urban supply is highly increasing due to expansions of different irrigation projects and urbanization. To overcome these problems alternative source of water should be required in addition to surface water. Therefore determination of groundwater recharge and its spatial distribution is necessary as a solution for such scarcity; also determination of crop water requirement of dominant crop produced by irrigation in this study area like potato is necessary.

In this study, a distributed water balance recharge estimation technique called WetSpass (Batelaan and DeSmedt, 2007) was applied to estimate long-term seasonal/annual average recharge as a function of land use/land-cover, soil type, topography and hydro meteorological factors. It is a physical based method for estimation of the long-term average, spatially varying, water-balance components: surface runoff, actual evapotranspiration, and groundwater recharge, which is ArcView based model to simulate all the results. It was successfully applied in different parts of the world in Gaza Strip, Palestine (Aish *et al.*, 2014) and other environments as in Poznan Plateau, Poland (Graf and Przybyłek, 2014) and Geba catchment, Ethiopia (Tesfamichael *et al.*, 2010), in Wari Watershed, Ethiopia (Gebremedhin and Asfaw, 2017), in Modjo sub-basin, Upper awash

(Negash, 2017), and in Birki watershed, the eastern zone of Tigray, Northern Ethiopia (Esayas and Gebeyehu, 2018). Based on those authors groundwater recharge was successfully estimated which is the main interest of this research.

CROPWAT is a computer programme that can calculate crop water and irrigation requirements from climatic and crop data. The programme is interactive in nature. In addition, the programme allows the development of irrigation schedules for different management conditions and the estimation of scheme water supply for varying cropping patterns. In this study the crop water requirements and irrigation requirements of the potato crop was calculated by using CropWat 8.0 model.

Hence, the overall objective of this research is to estimate spatial groundwater recharge and crop water requirement of potato in Holetta watershed, upper Awash River basin, Ethiopia, with the following specific objectives:

- To estimate spatial ground water Recharge in Holetta watershed.
- To estimate annual and seasonal groundwater recharge of the Holetta watershed.
- To estimate Crop water requirement CWR of potato in the study area.

2. LITERATURE REVIEW

2.1. Water Resources and Hydrologic Cycle

Water resource, which is the backbone and crucial element of life, is needed in sufficient quantity and quality to meet the increasing demand for domestic, agricultural and industrial processing operations (Fenta *et al.,* 2015; Al-Ruzouq *et al.,* 2015, Haile and Semir 2016). But, its availability is limited because of its natural distribution on the earth surface, in which 97.5% of the global water is saline existing in the oceans and only 2.5% is considered to be available for biological use, i.e., freshwater. The estimated volume of fresh groundwater is 10.53 million km^3, which is almost 99% of all liquid fresh water on Earth. The combined volume of the freshwater present in lakes are 91 thousand km^3, swamps had 12 thousand km^3, streams 2.1 thousand km^3 and the atmosphere 13 thousand km^3 (UNSCO-WWAP, 2006). It is a scarce, crucial and multi-functional natural resource found on the planet and the demand for fresh water is increasing worldwide as a result of urbanization, economic and population growth (Karimi and Bastiaanssen, 2015). Because of its scarcity, proper planning and management of such resource in terms of distribution, management, utilization, and environmental functions are crucial for optimizing the resource use sustainable (Karimi and Bastiaanssen, 2015).

The hydrological cycle is defined as a water transfer cycle occurs continuously in nature; at which the occurrences of evaporation and evapotranspiration, precipitation and runoff take 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 to the atmosphere, condenses and form clouds and then through a process of condensation, results from precipitation back to the earth surface. This precipitation flows as runoff to the oceans or infiltrates into the soil to be groundwater. This system of water circulation starts its cycle again and again and will not be stopped at one time (Gebremedhin and Asfaw, 2017).

Ethiopia is considered as a water tower of Africa next to Zaire, due to its plenty of water resources available on the surface and groundwater beyond the erratic rainfall it has. In contrary, MoWR (2011) have indicated that as compared to surface water resources, Ethiopia has lower Groundwater potential, which is estimated 12 to 30 Billion meter cubic but this figure appears to be extremely underestimated. The total exploitable groundwater potential is high as compared to other countries in Africa. But knowledge available on groundwater resources of Ethiopia is scanty. It needs to have a very detailed study on this issue so that enough information is available.

2.1.1. Groundwater resources

There are different definitions given to groundwater potential by different authors in a different time. Groundwater is the most important natural resources found beneath the earth surface stored in void space of geological stratum used in economic development, domestic life, and any ecological diversity Rashman (2016), and also, he concludes the occurrence and flows system of groundwater is depends on geological characteristics of its porosity and permeability and the formation of landforms such as high mountains, rift valley's and flat areas and the role of landform on surface runoff and infiltration to the ground.

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 freshwater resources (UNSCO-WWAP, 2006). The groundwater is therefore essential for storing the freshwater required by a human. Groundwater can also be stored in the saturated zone of the soil which serves as the largest reserve of drinkable water. This water can be accessed for human by different mechanisms as a form of springs, tapped by wells or drilled from boreholes. It is less contaminated by wastes and can sustain the flow of surface water during dry periods. Also, it is an important source of fresh drinking and irrigated water across the world and plays a vital role in mitigating the environmental values especially in arid and semi-arid regions (UN/WWAP, 2006; Holger *et al.,* 2012; Fenta *et al.,* 2015).

Groundwater is the source of water which accounts around 35% of global human water withdrawals, and even of 42% of global irrigation water withdrawals (Siebert *et al.,* 2010; Doll *et al.*, 2012). It is a more reliable and harmless water source than surface water, because its use is less restricted by seasonal or inter-annual flow variations (e.g. drought periods), and because it is much better protected from anthropogenic pollution. Due to the increased temporal variability of surface water flows, climate change is likely to lead to higher demands for groundwater (Kundzewicz and Doll, 2009, Taylor and Doll*,* 2013). In some semi-arid and arid regions with intensive irrigation, abstraction rates exceeding groundwater recharge have resulted in strong groundwater depletion (Wada. 2012).

2.1.2. Groundwater recharge

According to Rajaveni *et al*., (2015) groundwater recharge is the percolation or infiltration of water from unsaturated zone to saturated zone through porosity and a permeable layer of the earth materials above the water table and finalizes precipitation, infiltration/ percolation of the surface water to the subsurface influenced by geology and geomorphology. Also, he concludes the occurrence and flows system of groundwater depends on geological characteristics of its porosity and permeability and the formation of landforms such as high mountains, rift valley's and flat areas and the role of landform on surface runoff and infiltration to the ground. Permeability's of surface and subsurface materials can greatly affect recharge processes.

Recharge in a watershed depends on many different factors such as amount, distribution and frequency of rainfall across the watershed, land cover and land use, the area of bare soil, vegetation type, soil type and soil properties and the like. Thus, the recharge is not static but dynamic which varies in space and time. When one goes across various locations across a watershed recharge gets varied accordingly. The amount of groundwater recharge occurring at a given location is typically expressed as a depth of water across the watershed. Recharge amounts are expressed over some time. Recharge rate is expressed as a volume (depth) per given time. Due to variations and distribution of rainfall, drought in Ethiopia is a frequently recurring phenomenon. The spatial distribution and the frequency of its occurrence have increased in recent years (Walraevens *et al.,* 2009).

Recharge is more likely to occur in areas that have coarse-grained, high-permeability soils as opposed to areas of fine-grained, low-permeability soils. Coarse-grained soils have relatively high permeability and are capable of transmitting water rapidly (Leblanc *et al,* 2008; Healy, 2010). It is a sensitive function of the climatic factors, local geological formation, and topography and land use types of the area under consideration (Taylor and

Doll, 2013). As precipitation gets varied due to variations in climate change as a result of temperature and evapotranspiration, there is possibly variation in groundwater recharge.

For long Ethiopia's groundwater potential is believed to be of limited extent when compared to surface water resources, yet compared to other countries the total exploitable groundwater potential is high (Awulachew *et al.,* 2007; Kebede, 2013). The total annual recharge for entire Ethiopia is estimated to be 36billion m^3/year (Kebede, 2013). The distribution of this recharge however significantly varies spatially and temporally as it depends on a wide variety of factors such as climate, topography, vegetation, soil, and geology. Therefore, understanding the spatial and temporal variability of groundwater recharge is critical for sustainable development and management of groundwater resources. Although groundwater research has been done at different scales in Ethiopia, there have been few attempts (Ketema and Broder, 2009, Gebremedhin and Asfaw, 2017, Demissew, 2017 and Negash, 2017) to quantify the spatial and temporal variability of recharge.

2.1.3. Estimation of groundwater recharge

Groundwater recharge generally refers to the component of hydrologic cycle that reaches the groundwater table. Direct measurement of recharge is unfortunately not possible as the processes vary from place to place and time to time. There is no hard and fast rule to follow for estimation of recharge in any area because a method developed for a given locality will not give a reliable result when used in another locality. Quite often, groundwater recharge is estimated as a fraction of rainfall. However, estimation based on hydrologic model and hydrograph separation methods is commonly practiced by surface water hydrologists. A study by Luo *et al.* (2012) can be considered as a good example of a watershed model application for groundwater recharge estimation.

Recharge can be estimated using many approaches depending on the availability of data and the level of accuracy required. It can be estimated by different methods like, Base flow separation methods (Alemu, 2017); WetSpass model (Yibeltal, 2006; Gebremedhin and Asfaw, 2017; Demissew, 2017; Negash, 2017; Esayas and Gebeyehu, 2018). Recharge can also be estimated with numerical groundwater models using inverse techniques. However, models do not produce unique solutions, so should not be relied upon as a sole technique for estimating recharge. In arid and semiarid areas, recharge is relatively small and potentially more variable (Allison *et al.,* 1994). As such, the use of techniques that can handle spatial variability is necessary. In this regard, geographic information systems (GIS) have emerged as effective tools for handling spatial data and decision making in several areas including engineering, geology, and environmental fields.

Christoph *et al.* (2011) introduced a new approach for investigation of the unsaturated zone through a combined use of laboratory and field techniques in arid environments. This technique uses direct push techniques to get undisturbed soil samples, extraction of pore water for isotope analyses and application of Time Domain Reflectometry (TDR) to determine soil moisture content. Combination of these techniques resulted in a better quantification of present and historic groundwater recharge.

2.1.4. Hydrological Models

According to Moradkhani and Sorooshian (2008), a model is a simplified representation of real world system. The best model is the one which give results close to reality with the use of least parameters and model complexity. Models are mainly used for predicting system behavior and understanding various hydrological processes. A model consists of various parameters that define the characteristics of the model. A runoff model can be defined as a set of equations that helps in the estimation of runoff as a function of various parameters used for describing watershed characteristics. The two important inputs required for all models are rainfall data and drainage area. Along with these, watershed characteristics like soil properties, vegetation cover, watershed topography, soil moisture content, characteristics of ground water aquifer are also considered. Hydrological models are now a day considered as an important and necessary tool for water and environment resource management.

A hydrological model is a simplified representation of a real-world system and consists of a set of simultaneous equations or a logical set of operations contained within a computer program. Models have parameters, which are numerical measures of a property or characteristics that are constant under specified conditions. Computer modeling offers a methodology to investigate hydrological processes and make predictions on what the flow might be in a river given a certain amount of rainfall. There are different types of models, with different amounts of complexity, but all are a simplification of reality and aim to either make a prediction or advance our understanding of biophysical processes (Davie, 2008).

There are many hydrological models available today for estimation of groundwater recharge. These models are designed to work based on spatial and temporal distributions of the complex systems of groundwater recharge. Models can be categorized as conceptual, distributed, undistributed or stochastic, etc. based on their physical parameterization and model structure. Most of the models are rainfall-runoff models and or hydrological models. Most of the time, the terms rainfall-runoff models and or hydrological models are used interchangeably in literature (Obuobie *et al.,* 2008).

According to the input-output mathematical relationship, hydrological models can be divided into deterministic and stochastic models. Deterministic models are characterized by the same output when a single set of inputs is given, while in stochastic models a single set of inputs can produce very different outputs because of random processes within the model (Kenway *et al.,* 2011).

The distributed hydrological models characterize the catchment in details, but intensive data are required which are not available in most developing countries (Sandholt, *et al.,* 2002). However, if the catchment data (i.e., topography, soil, and land use maps) are available in addition to precipitation and evapotranspiration information, they have high importance in reproducing the runoff for the catchments with no stream flow record to assist water infrastructure investments (Vargas and Gourbesville, 2016). Distributed hydrological models represent the heterogeneity of the catchment by considering the spatial variability of hydrometeorological variables, topography, geology, soil type, and land use. Nevertheless, their complexity, long computation time and enormous data requirement lead them to have limited practicality in most contexts (Carcano *et al.*, 2008).

On the other hand, lumped hydrological models represent the catchment as a single unit. They are characterized by minimal data requirement which is averaged over the catchment.

In these types of models, the parameter values are determined through calibration, not from the physical behaviors of the catchment (Vargas and Gourbesville, 2016). Besides, the spatial inhomogeneity of the input variables and parameters are not represented, which limit their capability to simulate all of the hydrological processes of the catchment.

2.2. WetSpass Model

For the estimation of long-term spatial patterns of the groundwater recharge, that could be used as input in regional groundwater flow models and for the analysis of regional groundwater flow systems, a simplified model WetSpass was developed by Batelaan and DeSmedt (2001) based on WetSpa. WetSpass stands for **W**ater and **E**nergy **T**ransfer between **S**oil, **P**lants, and **A**tmosphere under **q**uasi-**s**teady **S**tate conditions, which is GIS-based, spatially distributed hydrological model for calculating the spatially distributed yearly and seasonal evapotranspiration, surface runoff, and groundwater recharge.

The model accounts for the spatial variation in the groundwater recharge, which is the result of distributed land use, soil type, slope, etc. Figure (1) gives a schematic water balance of a hypothetical grid cell for WetSpass from Batelaan and De Smedt (2001). The total water balance for a cell in a spatially distributed grid is split up in independent water balances for vegetated, bare-soil, open-water and impervious parts of the grid cell. This allows accounting for the non-uniformity of the land use depending on the resolution of the grid cell. The processes in each part of a grid cell are set in a falling way. This means an order of occurrence of the processes, after the precipitation event, is assumed. Defining such an order is a prerequisite for the seasonal time scale with which the processes are quantified.

2.2.1. Application of WetSpass model

In this study, WetSpass model was used to estimate spatial groundwater recharge at seasonal and annual scales based on some relationships. The application of this model is compatible and integrated with the GIS ArcView software during simulation process. The description and formulas below are based on Batelaan and De Smedt (2007) and used by (Gebremedhin and Asfaw, 2017) in Werii watershed, (Negash, 2017) in Modjo sub basin, (Esayas and Gebeyehu, 2018) in Birki watershed, the eastern zone of Tigray, Northern Ethiopia. Total water balance per raster cell and season are calculated using:

$$ET_{raster} = a_vET_v + a_sE_s + a_oE_O + a_i \quad (1)$$

$$S_{raster} = a_vS_v + a_sS_s + a_oS_O + a_iS_I \quad (2)$$

$$R_{raster} = a_vR_v + a_oR_O + a_sR_s + a_iR_i \quad (3)$$

$$P = I + S_V + T_V + R_V \quad (4)$$

where:-ET_{raster}, S_{raster} and R_{raster} evapotranspiration, surface runoff, and groundwater recharge [LT^{-1}] with subscript relating to a cell (raster), vegetation (v), bare soil (s), open water (o) and impervious area (i). The coefficient, a, expresses the contribution of each land use. Moreover, P, I, S_v, T_v and R_v represents the total seasonal precipitation, the interception by vegetation (precipitation that evaporates from the wet surface of the vegetation), the surface runoff over the land surface beneath the vegetation, the actual transpiration of the vegetated surface and groundwater recharge expressed in [LT^{-1}] units respectively.

$$ET_{tot} = I + T_v + E_s \quad (5)$$

ET_{tot} is the total actual evapotranspiration, I is evaporation from intercepted water by vegetation, T_V transpiration of vegetation cover and E_s is evaporation from the bare soil between the vegetation.

2.2.2. Water Balance per Raster Cell

Since WetSpass model is a distributed water balance model, the water balance computation is performed at raster cell level.

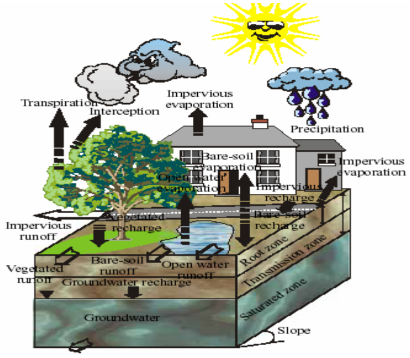

Figure 1. Schematic water balance of a hypothetical raster cell (Batelaan *et al.,* 2001)

Individual raster water balance is obtained by summing up independent water balances for the vegetated, bare soil, open water and impervious fractions of a raster cell. This allows, depending on the resolution of the raster cell, to account for the non-uniformity of the land-use per cell and soil type per cell (Figure 1). In general, the total water balance components, per raster cell and season, can be calculated using the water balance components for vegetated, bare soil, open water and impervious parts of the raster cell (Batelaan and De Smedt, 2007).

2.2.3. WetSpass Adjustment in the Case of Ethiopia

WetSpass is originally developed for environments in the temperate regions in general and Europe in particular (Batelaan and De Smedt, 2001, 2007). The land use and soils types and the number of weeks in a year that falls 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 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 summers 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 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.

The input data of the model are the climatic data include precipitation, reference evapotranspiration (ET_o), wind speed, and temperature, the catchment configuration includes land use, slope, and groundwater depth and also the model requires the soil data includes hydraulic properties in a grid format. The outputs of this distributed hydrological model are evapotranspiration, transpiration, soil evaporation; interception, runoff and groundwater recharge (Batelaan and De Smedt, 2007).

2.3. Description of CropWat Model

CropWat is a decision support system developed by the Land and Water Development Division of Food and Agriculture Organization (FAO) for the planning and management of irrigation (FAO, 1992). CropWat is a practical tool to carry out standard calculations for reference evapotranspiration, crop water requirements, and crop irrigation requirements, and more specifically the design and management of irrigation schemes. For this study, CropWat8.0 was used. CropWat8.0 is a computer programmed for the calculation of crop water requirements and irrigation requirements from existing or new climatic and crop data. Furthermore, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns. In CropWat8.0, the calculation of crop water requirements is carried out per decade (Allen *et al., 2005*).

The algorithm for calculation of crop water requirement (CWR) and irrigation need of CropWat is based on an estimation of potential evapotranspiration, using the Penman-Montieth equation (Allen *et al., 2005*), and crop parameters, as indicated in the flow chart (Figure 2). In addition to climatological records, this model required site location, i.e. altitude, latitude, longitude and name of the meteorological station. Crop water requirements depend on the balance between evapotranspiration and precipitation and resulting soil moisture condition. It is driven by meteorological conditions, crop management practices and by the amount of soil water available to their roots (Perira *et al.,* 2006).

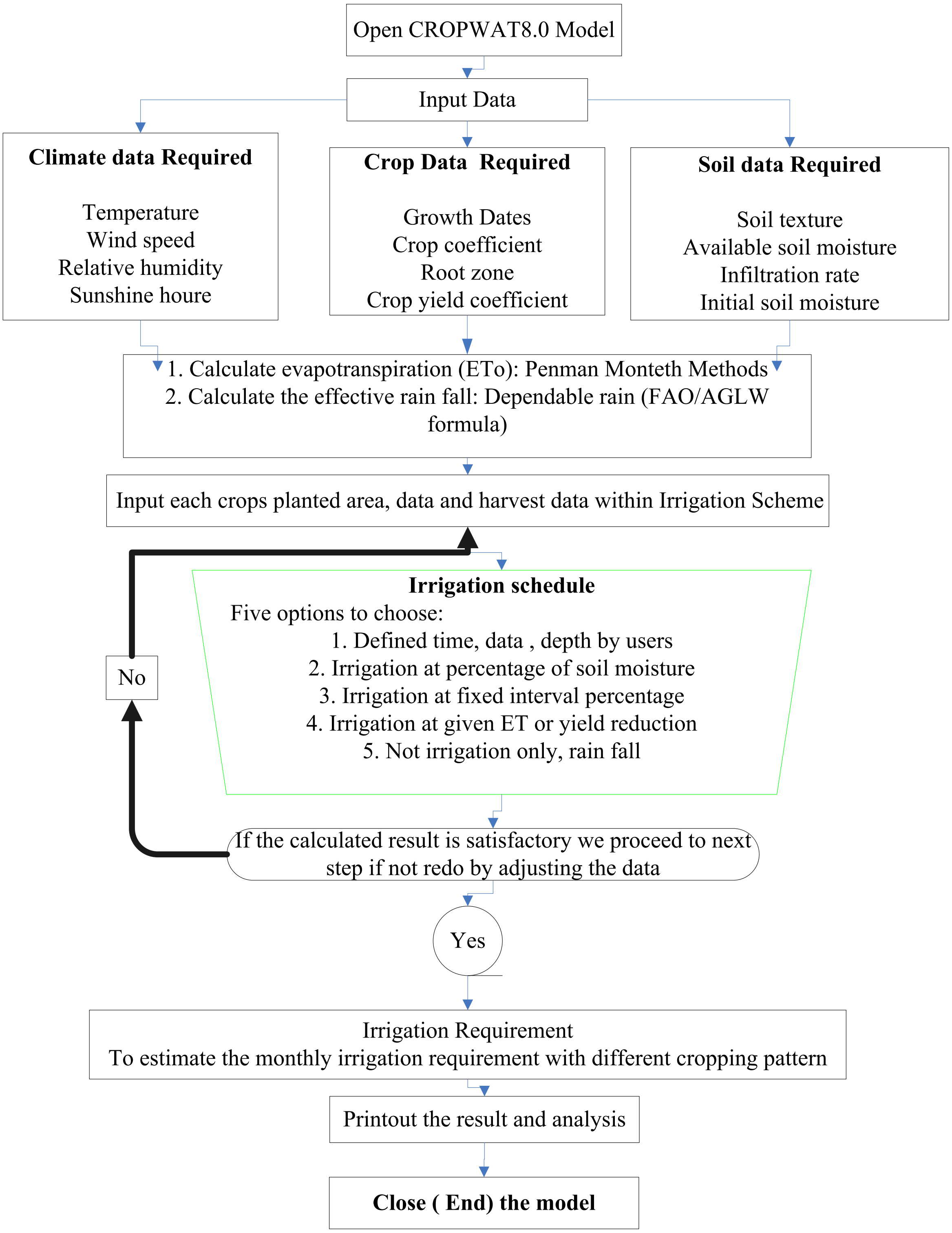

Figure 2. Flow chart of CropWat model to calculate the crop water requirement (Rufa, 2010)

2.3.1. Crop water requirement

Crop water requirement is the depth of water required to meet the water loss through evapotranspiration (ETc) of disses free crop, growing in large fields under non-restricting soil condition including soil water and fertility and achieving full production potential under the given growing environment (FAO, 1998). Although the values for crop evapotranspiration and crop water requirement are identical, crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration. The irrigation water requirement represents the difference between the crop water requirement and effective precipitation. The irrigation water requirement also includes additional water for leaching of salts and water to compensate for non-uniformity of water application. For the calculations of the Crop Water Requirements (CWR), the crop coefficient approach is used (FAO, 1998).

2.3.2. Crop coefficient approach

Crop evapotranspiration can be calculated from climatic data and by integrating directly the crop resistance, albedo and air resistance factors in the FAO Penman-Monteith approach. As there is still a considerable lack of information for different crops, the Penman-Monteith method is used for the estimation of the standard reference crop to determine its evapotranspiration rate, i.e., reference evapotranspiration (ETo). Experimentally determined ratios of ETc/ETo, called Crop coefficient (Kc), are used to relate crop evapotranspiration under standard conditions (ETc) to ETo. This is known as the crop coefficient approach (FAO, 1998).

$$ET_C = K_C \times ET_O \tag{6}$$

Radiation, Air Temperature, Humidity and Wind speed are all incorporated into the ETo estimate. Therefore, ETo represents an index of climatic demand, while Kc varies predominately with the specific crop characteristics and only to a limited extent with climate and soil evaporation. This enables the transfer of standard values for Kc between locations and between climates. This has been a primary reason for the global acceptance and usefulness of the crop coefficient approach and the Kc factors developed in past studies. The reference ETo is defined as the rate of evapotranspiration from an extensive surface of 8 to15 cm tall, green grass cover of a uniform height, actually growing, completely shading the ground and not short of water and calculated using the FAO Penman-Monteith equation (FAO, 1998) equation (11) . The crop coefficient, Kc represents an integration of the effects of four primary characteristics that distinguish the crop from reference grass. These characteristics are crop height, Albedo of the crop soil surface, canopy resistance, and evaporation from the soil, especially exposed soil (FAO, 1998).

The FAO Penman-Monteith equation predicts the evapotranspiration from a hypothetical grass reference surface that is 0.12 m in height having a surface resistance of 70 s m^{-1} and albedo of 0.23. It provides a standard to which evapotranspiration in different periods of the year or in other regions can be computed and to which the evapotranspiration from other crops can be related. Standardized equations for computing all parameters are given by equation (11), FAO *(*1998).

2.3.3. Effective rain fall

Effective rainfall is defined as that a part of the rainfall which is effectively used by the crop after rainfall losses due to surface runoff and deep percolation has been accounted for. The effective rainfall is the rainfall ultimately used to determine the crop irrigation requirements (Babu, *et al.,* 2015). This shows not all rain is available to the crops as some are lost through runoff and deep percolation. How much water actually infiltrates into the soil depends on soil type, slope, crop canopy, storm intensity, and the initial soils water content. During the rainy season in tropical and some semi-tropical regions, a great part of the crop's water needs is covered by rainfall, while during the dry season; the major supply of water should come from irrigation. How much water is coming from rainfall and how much water should be covered by irrigation is, unfortunately, difficult to predict as rainfall varies greatly from season to season. In order to estimate the rainfall deficit for irrigation water requirements, a statistical analysis needs to be made from long-term rainfall records (FAO, 1998).

To account for the losses due to runoff or percolation, a choice can be made of one of the four methods given in CROPWAT 8.0 Fixed percentage, Dependable rain, Empirical formula, and USDA Soil Conservation Service (Dastane, 1974). In general, the efficiency of rainfall will decrease with increasing rainfall. For most rainfall values below 100 mm/month, the efficiency will be approximately 80%. Unless more detailed information is available for local conditions, it is suggested to select the Option “Fixed percentage” and give 80% as requested value.

2.3.3. Dependable rainfall

Based on an analysis carried out for different arid and sub-humid climates, an empirical formula was developed in Water Service of FAO to estimate dependable rainfall, the combined effect of dependable rainfall (80% probability of exec dance) and estimated losses due to runoff and deep percolation. This formula used for design purposes where 80% probability of exec dance is required (FAO, 1998) it calculated by (equation 7 and 8).

To calculate the effective rainfall by dependable percentage in CROPWAT 8.0, open the model go to Rain, open setting, options, rainfall, select the dependable rain (FAO/AGLW Formula), then finally conform by Ok.

$$p_{eff} = 0.6 \times p \quad \text{For } p_{month}<70\text{mm} \tag{7}$$

$$P_{eff} = 0.8 \times p - 24 \quad \text{For } p_{month}>70\text{mm} \tag{8}$$

where,

P_{month}= monthly rainfall, mm and

P_{eff}= effective rainfall, mm.

3. MATERIALS AND METHODS

3.1. General Description of the Study Area

3.1.1. Location

The study was conducted in Holetta watershed, upper part of the Awash River basin, Ethiopia (Figure 3). The study area is geographically located at a latitude range of 8°56'N to 9°13'N and longitude range of 38°20'E to 38°40'E. It is a catchment with a drainage area of 415.7 km^2. Holetta town which is the capital of the Wolmera Genet area the major settlement area in the watershed and 45 km in the west direction from Addis Ababa. The total length of streams in the catchment is about 45.51 km. About 5 km north of Holetta town is the conjunction of the Holetta and the Mintile River, which originates in the mountains. At the end, the Holetta River joins with Awash River at Ilu Woreda.

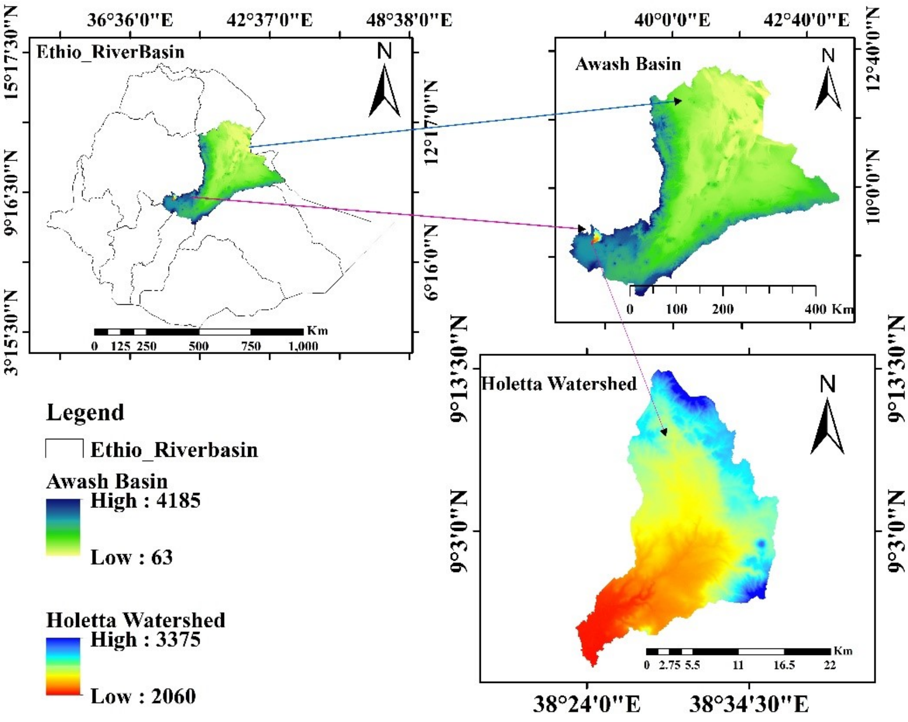

Figure 3. Location map of the study area

3.1.2. Rainfall and temperature

The Ethiopian climate system is traditionally classified based on existing altitudinal range and temperature. Hence, there are five climatic zones in the country. The *Berha* zone is a very hot and hyper-arid region with less than 500 m.a.s.l. and *Kola zone* is also a hot and arid region ranged between 500-1500 m.a.s.l. altitudes. Similarly, *Woina-Dega* is an optimum temperature from 1500-2500 m.a.s.l. altitude. *Dega* and *Wurch* zones are found in highland regions with 2500-3000 m.a.s.l and greater than 3000 m.a.s.l. altitudes respectively (NMA, 2001). According to this classification, Holetta watershed is laid in between *Woina-Dega, Dega,* and *Wurch* with majority fall in *Woina-Dega* zone.

The average annual rainfall of the watershed varies from 993 mm to 1106 mm. The rainfall distribution is bimodal in *Dega* part of the watershed: short rains, *Belg,* last for four months, from last weeks of January to April; and long rains, *Meher,* from June to September. The rainfall is mono-modal in *Weyina Dega* part of the watershed last long. The average highest rainfall of the study watershed is recorded in July and August 239 mm and 223 mm respectively. The annual mean temperature is 16.5°C with April being the hottest month. The mean highest temperature in Holetta watershed is 26°C, with December the coldest month with an average lowest temperature of 5°C. As shown in (Figure 4) below. The long term average monthly rainfall of all stations used in this study is given in Appendix Table 1.

3.1.3. Relative humidity

The monthly relative humidity of Holetta watershed is given in table 1 shows that the average percentage relative humidity is maximum in August and minimum in February 91% and 46% respectively. The mean annual relative humidity of the watershed is 63%. The summer and winter is 84% and 53% respectively (Table 2). This show that the watershed is very humid in the summer (wit seasons).

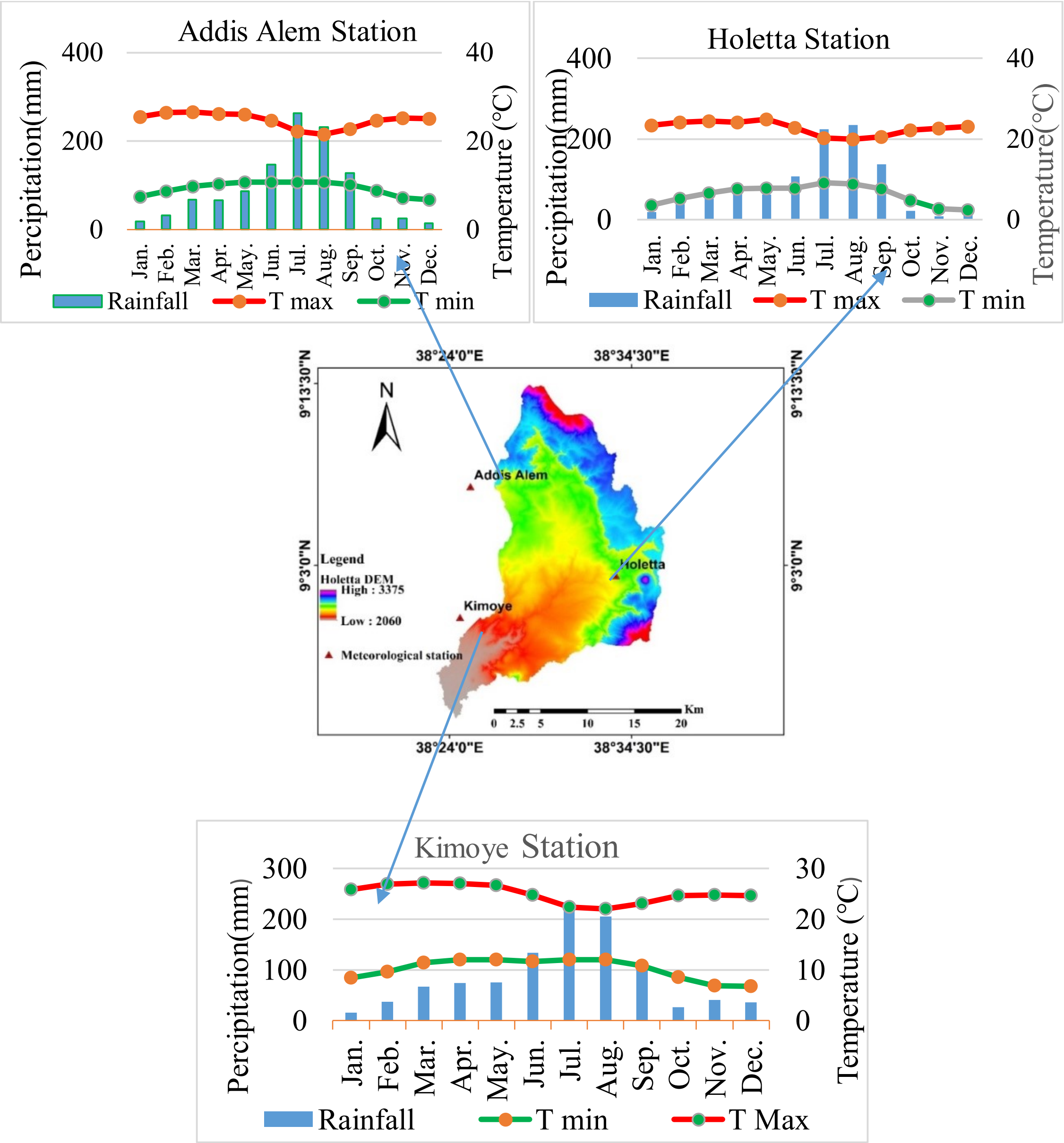

Figure 4. Mean monthly rainfall and temperature of the stations

Table 1. Monthly Relative humidity of the meteorological stations (%)

Stations	Jan	Feb	Mar	Apr	Ma	Jun	Jul	Ague	Sep	Oct	No	Dec
Holetta	49	46	51	58	54	74	93	94	83	64	54	50
Addis Alem	50	47	52	56	54	78	90	88	74	59	54	50
Kimoye	51	46	50	57	52	70	88	90	79	62	54	52
Mean	50	46	51	57	53	74	90	91	79	62	54	51

Table 2. Annual, Summer and Winter Relative humidity of the meteorological stations (%)

Stations	Winter	Summer	Annual
Holetta	53	86	64
Addis Alem	53	83	63
Kimoye	53	82	63
Mean	53	84	63

3.1.4. Wind speed

The seasonal variation of the inter-tropical convergence zone (ITCZ) influences the wind Flow direction. The predominant wind direction from June to September is southerly to southwesterly

3.1.5. Soil type

The soil map of the watershed was clipped from Ethiopia soil map that has been mapped at 1:250,000 scale. It was obtained from the Ministry of Water Irrigation and Electricity. Then the clipped soil map of the watershed is prepared as input using ArcGIS 10.4 software to identify soil type of the watershed area.

3.1.6. Topography

The topography of Holetta watershed is classified into different land structures and slope categories. The minimum and maximum elevations of this watershed are about 2060 m.a.s and 3375 m.a.s.l respectively. The maximum elevation is located in the North and southeast of the watershed. But, the minimum elevation is located in the southern part of the watershed. The average elevation is 2462 m.a.s.l as shown by (figure 5).

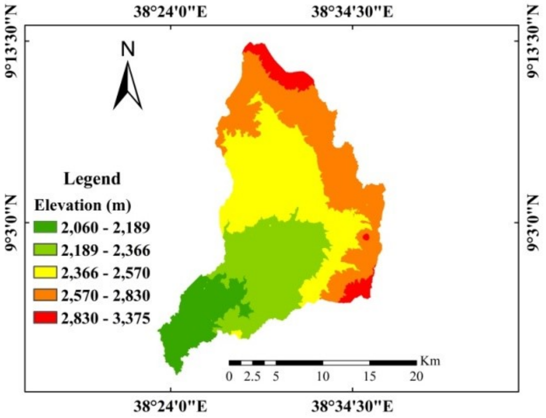

Figure 5. Elevation map of Holetta Watershed

3.1.7. Land use data

The land use/land cover pattern of a region is an outcome of natural and socio-economic factors and their utilization by a man in time and space. The terms land use and land cover are often used simultaneously to describe maps that provide information about the types of features found on the earth's surface is called as land cover and the human activity that is associated with them (Manugula *et al.,* 2017). Information on Land Use and Land Cover (LULC) is fundamental to water resources management. This information is used for the estimation of root zone depth, interception capacity and hydro-tope delineation (Winsemius, 2009) and for computing evapotranspiration (ET) in a river basin (Cheema and Bastiaanssen, 2010).

The land use/land cover data of the watershed was downloaded from www.earthExplorer.com website. The land use land cover data of summer and winter season were downloaded on 15th August 2017 and on 18th January 2018 respectively. The Landsat 8 image of the watershed was found on *169 paths and 054 rows* respectively. Then the bands added to ArcGIS 10.4 software to develop the land use and land cover class of the watershed 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 watershed. After adding the bands from band (B1 up to B5,) we classify by image analysis classification tool in Arc GIS, then export the composites of band, add the shape file of the watershed to Arc GIS software, extract by masking the watershed land use land cover as similar to the shape of the watershed. Finally, the land use land cover class was classified by supervised classification techniques (Figure 6).

In this study supervised image classification technique was applied following the steps suggestion by Hansen *et al.*, (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.

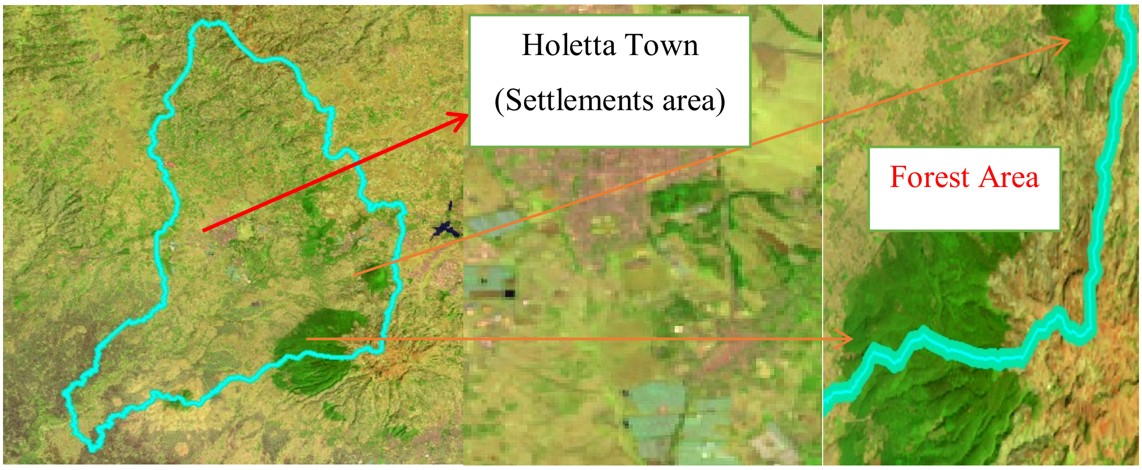

Figure 6. Map shows land sat 8 image of the study area

3.1.8. Farming system

In Holetta watershed different varieties of crops are grown at different seasons. During the main rains seasons, Wheat (*Triticum aestivum, L.),* Barley *(Hordeum vulgare L.), Teff* (*Eragrostis tef, L.),* Sorghum *(Sorghum bicolor, L. (Moench.)),* and different vegetables are produced. The dominant vegetables grown in irrigated land are potatoes, tomatoes, onion, Ensete (Ensete ventricosum), carrot, cabbage; and fruits such as Apple. The livestock sector comprises cattle, equines, sheep and goats and poultry. Apiculture sector also supports farmers in income generation Wolemera woreda agricultural office (WWAO, 2018). Commercial agriculture as a farming system has only emerged very recently. However, access to land and infrastructure as well as investment security are major promoters to the growth of this system of production. Flower Agriculture is the biggest investment in the watershed, at Wolmera woreda.

In addition to Holetta agricultural and research center and Tsedey Farm, smallholder farmers in four kebele's in the downstream use the Holetta river for irrigation which was considered as the major users of the river. These are *MediGudina, DewanaLafto, Tulu WatoDalecha*, and *Hamus Gebeya.* Farmers in these kebele’s grow cereals under rain-fed agriculture from June to November for subsistence. Potatoes and tomatoes are the dominant irrigated horticultural crops grown in this watershed (Mahtsente and Birhanu, 2015).

3.2. Data Collection

For this study hydrological and meteorological data collected are; daily precipitation, minimum and maximum temperatures, wind speed, sunshine hours, relative humidity from national meteorology agency of Ethiopia and daily stream flow of the study area was taken form minister of water, irrigation and electricity. Then the flow chart as shown in (Figure 7) was followed as general methods to estimate groundwater recharge.

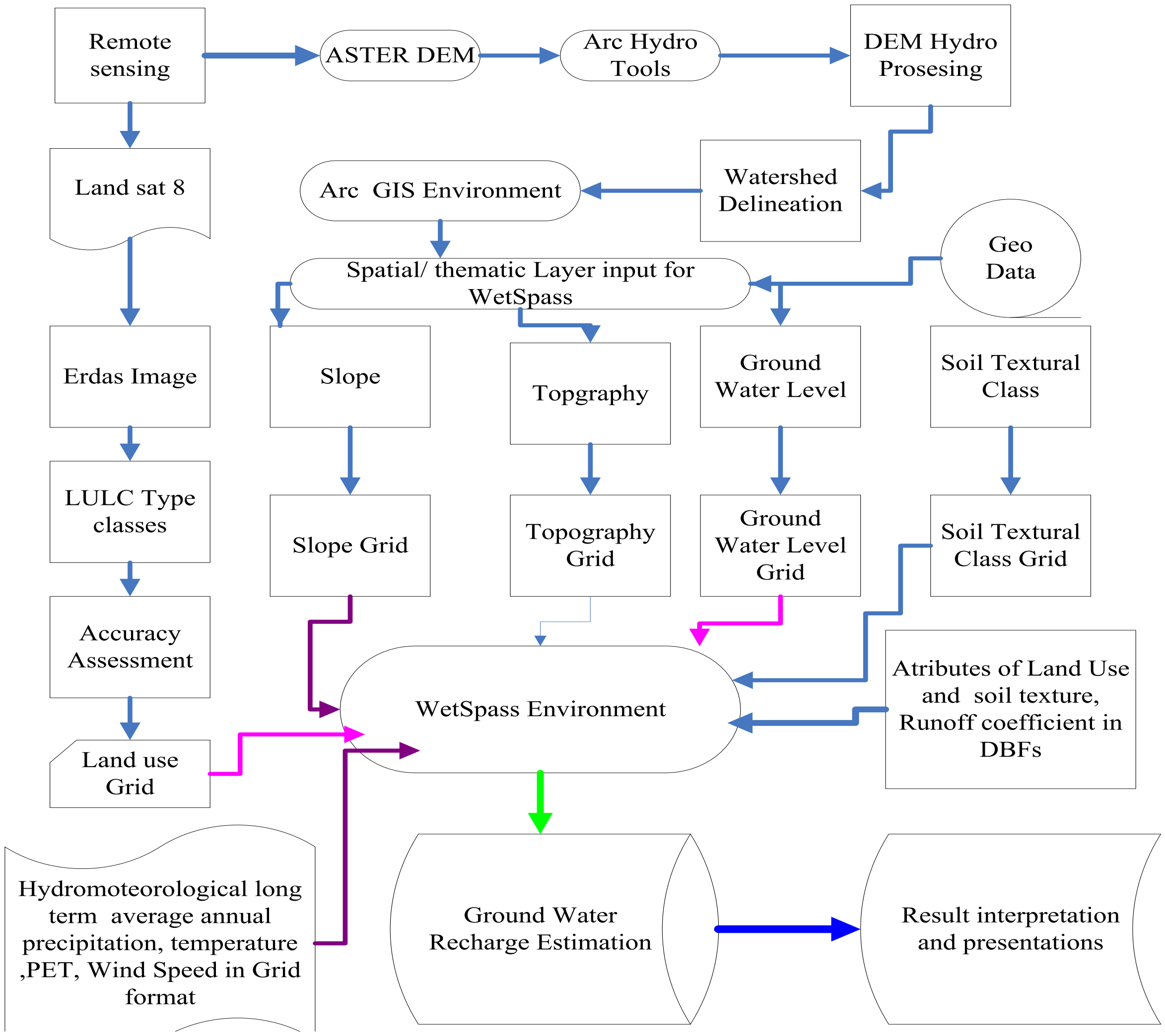

Figure 7. Flow chart of WetSpass model to run and analysis

3.2.1. Delineation of the watershed

The foremost activity in the hydrological watershed modeling task is the delineation of the watershed boundary. To delineate the watershed a DEM of 30mX30m resolution was downloaded from www.EarthExplorer.com and processed by ArcGIS 10.4. The outlet point of this watershed is found at 38°42'56"E and 8°55'7"N. The total area of the watershed becomes 415.7 km^2. The topographic and slope map of the Holetta watershed has been generated from the DEM of 30m x 30m resolution using ArcGIS 10.4 Spatial Analyst Tools.

3.2.2. Soil map

The Holetta watershed has four soil categories. These are Chromic Luvisols (Chluvisols) with an area of 34.03% which covers northern and southeastern part of the watershed, Humic Nitisols (Huntisols) 51.94% it covers the central parts of the watershed, Vertic Cambisols (Vtcambisol) 3.82% it covers northwestern parts of the watershed, and Eutric Vertisols (Euvertisols) 10.21% covers the southern parts of the watershed (Appendix Table 6). Based on their texture, Vtcambisol and Euvertisol are classified as clay, whereas Chluvisols and Huntisols are classified as loam (Mahtsente and Birhanu, 2015). This indicates the soil textural class of the watershed is dominated by loam and clay. They cover 85.97% and 14.03% in the watershed area respectively (Figure 8).

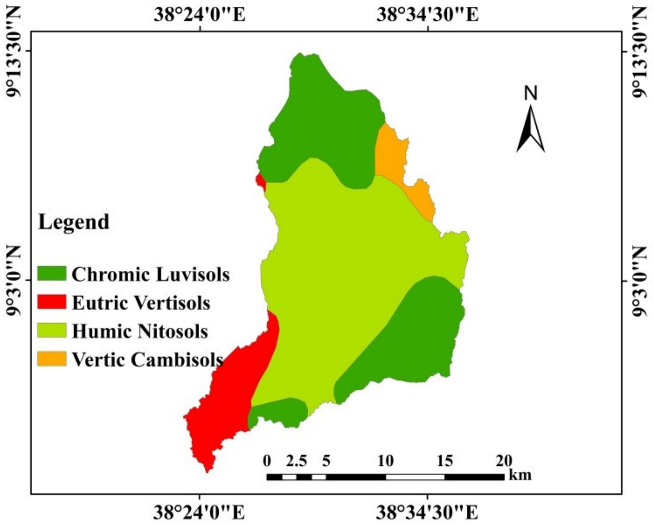

Figure 8. Soil map of Holetta Watershed

3.3. Materials and Software Used

Relevant and appropriate materials are very essential before doing of any work to achieve the objective of the research. Therefore the primary task of this study was collecting the required data from a different source by considering the objective of the study. Materials and software need for the successes of this study are given in Table 1 with their respective use.

Table 3. Purposes and description of the materials and software's used

No	Materials and software's	Purpose and description
1	GPS	Used to take the latitude and longitude point during data collection and to indicate right direction.
2	DEM	Used for Watershed delineation and to generate slope length(L) and slope steepness(S)
3	Digital camera	Taking existing land use and structures.
4	ArcGIS 10.4	Used to prepare land use land cover map and to delineate the watershed of the study area. It is also used with the model (WetSpass) to do all the activities.
5	Google Earth	Ground truth collection and feature identification, and to take GCP for inaccessible areas
6	WetSpass models	Used to run the collected data and process the out puts.
7	CROPWAT8.0 model	This software is used for determination of CWR.
8	Core sampler	Used to take soil sample.
9	Double-ring infiletrometer	Used for measuring of infiltration rate of the soil.
10.	XLS to DBF converter software	To prepare to lookup parameter tables of soil texture, land use land cover, runoff coefficient in DBF format
11.	Erdas imagine	Layer stacking, LULC classification, and accuracy assessment
12.	Ms-office 2013	Report writing and presentation

3.3.1. Meteorological and hydrological data

All the meteorological data (rainfall, minimum and maximum temperature, wind speed, relative humidity, and sunshine hour) were collected from national meteorological Agency (NMA) for the period of 1987-2015. The meteorological stations are Holetta and Kimoye and Addis Alem stations which are found around the watershed. River flow data from 1994-2009 and GIS data such as soil map were collected from the Ministry of Water, Irrigation, and Electricity (MoWIE).

3.3.2. Digital elevation model (DEM)

For this specific study, DEM with a resolution of 30m by 30m was used (Figure 9). The digital elevation map of the area was processed using ArcGIS 10.4 to delineate the watershed and analyze the drainage pattern of the land surface terrain as shown by Figure 10.

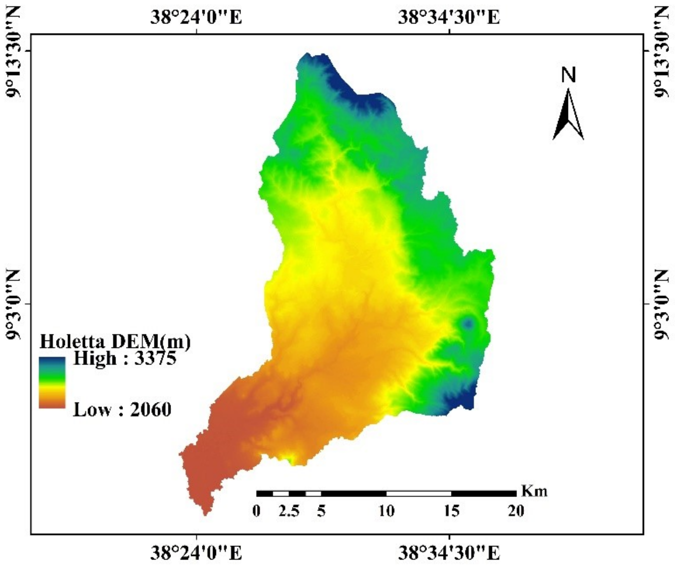

Figure 9. Holetta Watershed DEM

3.3.3. Filling of missing data

Missing data is one of the foremost problems which are frequently come across in meteorological data analysis due to the construction of a new building, fence, changing of gauge location, planting of trees or cutting of forest neighboring or another from a recording gauge. In this study, the missing data were adjusted by the normal ratio method, because, the percentage of missed data of the stations in this watershed and the nearest is greater than 10% (equation 9). It is enhanced than the arithmetic mean methods as recommended by Chow *et al.,* (1988).

$$P_x = \frac{N_x}{N}\left(\frac{P_1}{N_1} + \frac{P_2}{N_2} + \cdots + P_n/N_n\right) \quad (9)$$

where :- px= missing rainfall data at station x

N = number of neighboring rain gauges

N_1, N_2 and N_n are normal annual rainfall at station

P_1, p_2 and P_n are rainfall data at the neighbouring station

3.3.4. Consistency test

In this study, the consistency of the meteorological stations was checked by using double-mass curve methods. A consistent record is one where the characteristics of the record have not changed with time. It is a graph of the cumulative catch at selected the rain gauge station versus the cumulative catch of grouped gauges in the region that has been subjected to similar meteorological occurrences and arranged in reverse chronological order (are calculated starting from the latest record (Chow *et al.,* 1988).

$$P_x' = P_x \times \frac{M'}{M} \tag{10}$$

where: -

$\boldsymbol{P'_x}$ = corrected precipitation at station x

$\boldsymbol{P_x}$ = original recorded precipitation at station x

M' = corrected slope of the double mass curve

M = original slope of the double mass curve

3.3.5. Homogeneity testing of rainfall data

Homogeneity is an important issue to detect the variability of the data. In general, when the data is homogeneous, it means that the measurements of the data are taken at a time with the same instruments and environments. However, it is a hard task when dealing with rainfall data because it is always caused by changes in measurement techniques and observational procedures, environment characteristics and structures, and location of stations. In this study, the homogeneity of rainfall of the watershed was tested by using Xlstat 2015 software for each metrological station as shown in Table 8.

3.4. Model Input Data

WetSpass is a physically-based model which basically involves up to date physical and empirical relationships for its efficiently running processes. Climatic characteristics, catchment configuration, vegetation, soil properties, and boundary conditions are the five essential categories of input data necessary to do a watershed simulation with WetSpass. The climatic data include precipitation, reference evapotranspiration (ETo), wind speed, and temperature. The catchment configuration includes land use, slope, and groundwater depth. The soil data includes hydraulic properties and empirical coefficients whereas the boundary conditions include the extent of the area to be modeled. All the input data should be prepared in an ASCII grid format. Groundwater models like WetSpass used for analyzing groundwater systems at steady-state and, therefore, needs long-term average groundwater depth input.

In order to work with the model efficiently, all data has to be prepared in a seasonal manner (summer and winter season) and annually. Grid maps and parameter tables are required as inputs for the WetSpass model and are prepared with the help of Arc GIS software tools. These grid maps are land-use, soil, slope, topography and seasonal groundwater level, precipitation, potential evapotranspiration, and wind speed. The input files prepared as parameter tables were arranged in the database file format (.dbf).

The WetSpass model only considers the depth of groundwater table if it is near to the land surfaces. This depth of groundwater table is far from the surface in Holetta watershed. Generally, it is estimated deeper than twenty meters from the surface in the intact watershed. Different studies in Ethiopia indicate that depth of groundwater is far below the ground surfaces. For example, in a study conducted at Becho and Koka area, the groundwater level is very deep. Its average groundwater level is greater than 20 meters deep (WWDSE, 2008) and studies in Modjo sub-basin, upper awash also greater than 20 m (Negash, 2017). Geographically, Holetta watershed is found at the upper awash in the vicinity of Modjo, Becho and Koka area watershed. This groundwater depth makes an insignificant effect on the WetSpass model result. For these study 25 well data that are found in Holetta watershed and near the watershed was taken for both summer and winter groundwater depth and the map was prepared as an input grid map to the model.

3.5. Parameter Table Preparation and Look up Tables

Lookup tables are also important for running the WetSpass model, so that, four parameter tables were prepared; they are summer and winter land use land cover, soil texture and runoff coefficient parameters in DBF (database file) format. Basically, the model user guide and some other scholarly published literature reviews were used to adjust and develop the parameter values to the watershed characteristics. In this section, Excel (XLS) file to DBF file format converter software was used to prepare the lookup tables and these parameter tables are mentioned in (Tables 4, 5 and 6) respectively.

However, some of the seasonal land use parameter values are readjusted to fulfill the conditions in the study area as it has been used by (Tesfamichael *et al.,* 2010 and Negash, 2017). The highlighted portion of the table indicates the amended values for the study watershed. The developed grid maps and the parameter data together make the required interaction among each other to produce appropriate average values during the simulation processes. As a result, the output grid maps were simulated with the help of a spatial analyst tool in the arc view GIS environment.

Table 4. Look up parameters for winter land use land cover

NUM BER	LUS_TYPE	RUNOFF _VEG	NUM_V EG_RO	NUM _IMP	VEG_ AREA	BARE _ARE	IMP_ AREA	PENW_ AREA	ROOT_ DEPTH	LAI	MIN_ STOM	NTER C_PE	VEG_ HEIGH
307	Grass Land	grass	2	0	1.0	0.00	0.00	0.00	0.30	2.0	140.0	10.00	0.120
1	Settlement	Grass	2	1.0	0.20	0.0	0.80	0.00	0.30	2.0	100.0	10.0	0.12
7	Bare land	Bare soil	4	0.0	0.20	0.70	0.100	0.00	0.05	0.0	110.0	1.0	0.001
8	Pasture land	savanna	3	0	0.8	0.1	0.1	0	2	4.5	215	34	6
21	Agricultural area	Crop	1	0	0.00	1.00	0.00	0.00	0.35	2.0	180.0	20.0	0.6
33	Forest	Grass	1	0.0	0.20	0.80	0.0	0.00	0.60	0.0	110.0	30.0	2.0

Table 5. Look up parameters for summer land use land cover

NUM BER	LUS_TYPE	RUNOFF_ VEG	NUM_V EG_RO	NUM _IMP	VEG_ AREA	BARE _ARE	IMP_ AREA	PENW_ AREA	ROOT_ DEPTH	LAI	MIN_ STOM	NTER C_PE	VEG_ HEIGH
307	Grass Land	Grass	2	0	1.000	0.000	0.000	0.000	0.300	2.0	140.0	10.00	0.1200
7	Bare land	Bare soil	4	0	0.2	0.7	0.1	0	0.05	0.1	110.0	27	0.00
1	Settlement	Grass	2	2	0.6	0.1	0.3	0	0.30	2.0	100.0	10	0.12
36	Shrub land	Grass	2	0	08	0.2	0.0	0	0.60	0.0	110.0	5	2.0
33	Forest	forest	3	0	0.8000	0.0000	0.2000	0.0000	2.5000	7.50	375.00	50.00	10.000
21	Agricultural area	Crop	1	0	0.9	0.0	0.1	0	0.35	0.0	180.0	0	0.60

Land use land cover lookup table descriptions: *Num* number, *luse_type* land use type, *Runoff_veg* runoff vegetation, *Num_veg_Ro* runoff class for vegetation type, *Num_imp_Ro* imperviousrunoff class for impervious area types, *Veg_area* vegetated area, *Bare_area* bare area, *Imp_area* impervious area, *Openw_area* open-water area, *Root_depth* root depth, *Lai* leaf area index M*in_stom* minimum stomatal opening, *Interc_per* interception percentage, *Veg_height* vegetation height.

Table 6. Look up parameters for soil texture

Num	SOIL	FIEID_CAPA	WILTING_PNT	PAW	RESID_WC	AL	EVAPO_DEPT	TENSION_HH	P_FRAC_SU	P_FRAC_WIN
6	Silt	0.3	0.10	0.20	0.04	0.35	0.05	0.61	0.09	0.01
12	Clay	0.5	0.33	0.13	0.09	0.21	0.05	0.37	0.95	0.85
5	Loam	0.25	0.12	0.13	0.027	0.37	0.05	0.11	0.15	0.02

Soil textures attribute table descriptions: *Num* soil type number, “*Soil”* soil type, *Field Capac* field capacity, *Wilting PNT* wilting point, *PAW* plant available water content, *Resid WC* residual water content, *A1* calibration parameter dependent on the sand content of the soil, *Evapo depth* bare soil evaporation depth, *Tension HH* tension saturated height, *P_Frac_Sum* fraction of summer precipitation contributing to hortonian runoff, *P_Frac_Win* fraction of winter precipitation contributing to hortonian runoff.

3.6. Groundwater Depth

Representative static water level was taken from 25 different boreholes, which are collected in the watershed and in the vicinity of area (Appendix Table 7). 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 1 m (Yibeltal, 2006, Nehash, 2017).

3.7. Estimation of potential evapotranspiration

In this study, FAO-Penman-Monteith equation method is used to estimate the reference evapotranspiration of the watershed. It widely used thought the world as recommended methods by FAO (equation 11).

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \tag{11}$$

where:

ETo = is the daily reference evapotranspiration (mm day^{-1})

R_n = net radiation at the crop surface (MJ m $^{-2}$ day $^{-1}$)

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

T = air temperature at 2 m height (°C) u_2:

U2= wind speed at 2 m height (m s $^{-1}$) -

e_a = actual vapor pressure (kPa)

e_s = saturation vapor pressure deficit (kPa) :

Δ is the slope of vapor pressure curve (kPa °C^{-1}) and

γ = is the psychometric constant (kPa °C^{-1}).

3.8. WetSpass Result Analysis

WetSpass gives various hydrologic outputs on yearly and seasonal (summer and winter) basis. Even though the model is originally developed mainly to compute the long-term average spatially distributed recharge of a basin, it also simulates runoff, interception, transpiration, evapotranspiration, soil evaporation and the error in water balance. The calculation is performed for each time scale and on each grid or cell, a small plot of land of known size in the catchment. The grid size (or cell size) for this particular study is 30 m. This means that every grid cell on the GIS map represents a plot of land of size 900 m^2.

The results from the model can be analyzed in various ways. In the next section of this chapter, analysis of Annual, summer and winter output differences, analysis of spatial variations of recharge, evapotranspiration and runoff, as a function of land use, elevation and soil type, has been done.

The topography grid map, recharge and evapotranspiration grid maps have been combined for ease of analyzing the relationship between elevation with evapotranspiration and recharge. The land use and soil maps have also been combined with the recharge and surface runoff output maps to visualize the impact of different land covers and soil texture on the groundwater recharge and surface runoff respectively.

3.9. CROPWAT Model Analysis

Reference evapotranspiration, effective rainfall, crop pattern data, and soil data are required to run the CROPWAT model. After all, data is analyzed the crop water requirement of the major crop produced by irrigation during the dry period like potato (Solamum tuberosum L.) is calculated. The development stages, Kc factor and root depth of the crop were taken from FAO Irrigation and Drainage Paper 24 and 33 (FAO, 1992) and (FAO, 1986) for this study.

3.9.1. Analysis of soil data

The soil data required by the CROPWAT model are total available soil moisture (TAW) which is the difference between field capacity (FC) and permanent wilting point (PWP) which are determined by the pressure plate apparatus technique, maximum rain infiltration rate, maximum root depth of the crop, initial soil moisture depletion and initial available soil moisture(determined by using oven-dry). The soil sample was taken by identifying areas which are dominantly covered by potato crop. It was collected by using core sampler, at a different depth, 0-20 cm, 20-40 cm and 40-60 cm level (Appendix figure 1). The collected soil sample was analyzed in a laboratory at Haramaya University.

3.9.2. Measuring of the infiltration capacity of soil

The infiltration characteristics of the soil in this study area was identified by measuring the infiltration rate of the soil using instruments which is known as double ring infiletrometer. This measurement was taken by identifying the representative area of major potato production places in the watershed.

First we have selected the area that have very gentile slopes and which is not cultivated at least for one year. The two rings of 30 and 45 cm diameter are driven into the ground by a driving plate and hammer, to penetrate in to the soil uniformly without tilt or undue disturbance of the soil surface to a depth of 15 cm. After driving is over, any disturbed soil adjacent to the sides tamped with a metal tamper. Point gauges are fixed in the Centre of the ring and in the annular space between the rings.

Water was poured into the rings to maintain the desired depth 2.5 to 15 cm with a minimum of 5 mm and the water was added at regular time interval of 5, 10, 15, 20, 30, 40, 60 minutes, etc. up to the infiltration rate become constant and then plotted as infiltration rate in cm/hr. versus time in minutes. Then the unit of the measurement should be converted to mm/day to run with CROPWAT model.

3.9.3. Estimation of Crop water requirement and irrigation requirement

To estimate the crop water requirements and irrigation requirements, evapotranspiration, effective rainfall, data of crop, area coverage and soil data was fitted in to CropWat 8.0 model. All calculation procedures used in CropWat 8.0 were based on the FAO Irrigation and Drainage paper 56 (FAO, 1998).

The crop water requirement (WR) is calculated by multiplying the reference crop evapotranspiration, ETo, by a crop coefficient, Kc following Allen *et al* (1998) equation 12.

$$\mathrm{WR} = (\mathrm{ET_o} \times \mathrm{K_c}) + \mathrm{LR} \qquad (12)$$

Where:
WR= Irrigation water requirements for crop (m^3/day)
Kc= crop coefficient [dimensionless].
ETo= reference crop evapotranspiration (mm/day)
LR= leaching requirements’ (it is assumed 20% of the total applied water).

4. RESULTS AND DISCUSSION

4.1. Spatial Data Adjustment for Model Input

4.1.1. Watershed delineation

The delineated Holetta watershed has an area of 415.7 km^2. This map was masked and used for the preparation of the entire grid map used in this study as input for the WetSpass model (Figure 10).

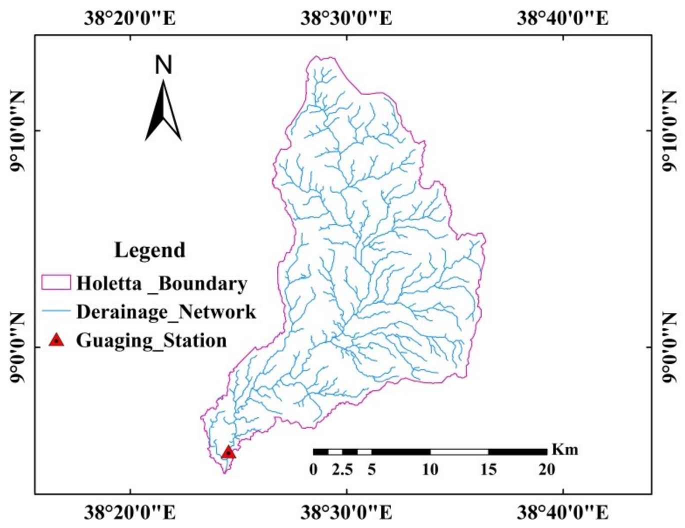

Figure 10. Drainage pattern of Holetta Watershed

4.1.2. Slope

The majority of the slope is class 1 (slope angle range of 0 to 10%) with 58.1% and class 2 (slope angle range of 10 to 30% and 27.5%, respectively. The majority of the steep area (more than 30% in slope angle) is around the north and southeast of the study area as shown by Figure 11. The slope is one of the factors controlling the infiltration of water to the ground and the indicator of groundwater potential suitability. High sloping regions produce more runoff and less infiltration and have poor groundwater prospects compared to the low slope region. Low slopping regions causes less runoff and high infiltration rate and have good groundwater prospect (Hsin *et al.*, 2016).

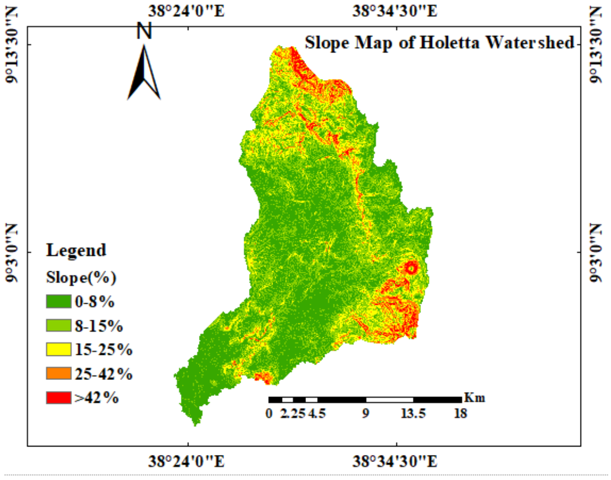

Figure 11. Slope map of Holetta watershed

4.1.3. Result of filled precipitation data of the meteorological stations

The result of missing meteorological data is given in Table 7. The missing data was calculated by normal ratio methods (equitation 9).

Table 7. The meteorological stantions used for this study with their Co-ordinates pointes

Name of the stantions	UTM Pointes Longitude (x)	Latitude (y)	Elevation (m)	Years	% of missing data
Holetta	998813	445287	2385	1987-2015	8
AddisAlem	999552	432225	2372	1987-2015	12.5
Kimoye	995802	427218	2150	1987-2015	13

4.1.4. Consistency test result

If the rainfall data recorded is consistent for the period of record, the double-mass curve should have a constant slope if it hasn’t constant slope it is inconsistent. Therefore; it should be corrected by equation (10). The meteorological data in this watershed are consistent as shown on Figure 11.

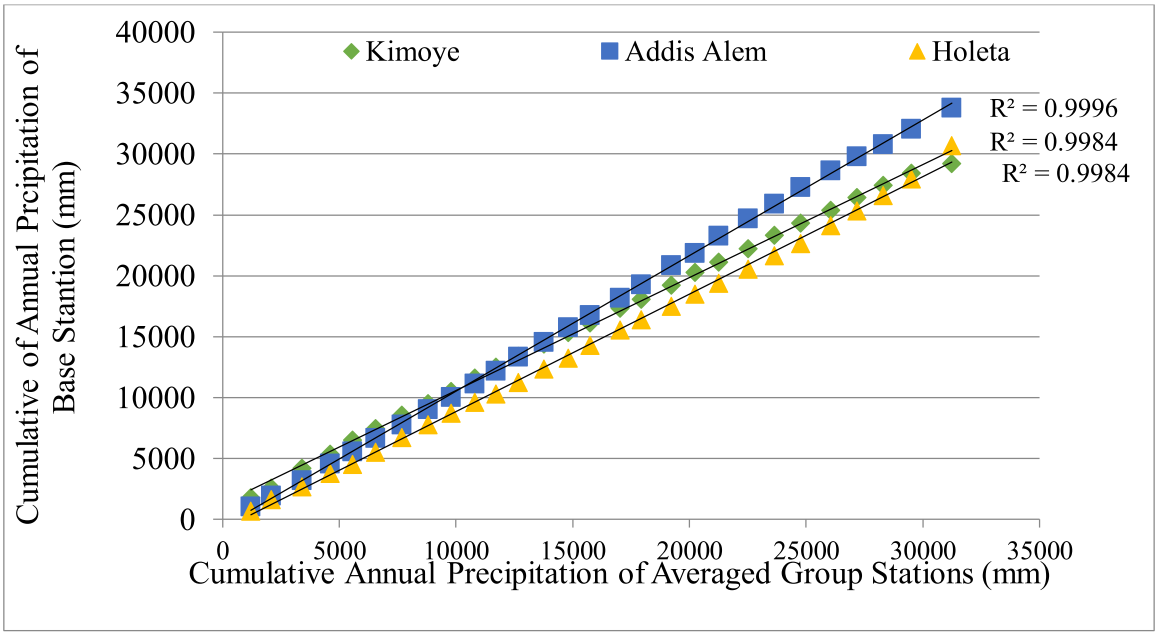

Figure 12. Consistency test of the rainfall in the study area

4.1.5. Results of Homogeneity tested rainfall data

The homogeneity of the meteorological stations in this study was checked by XLstat as discussed in chapter three. The greater P-value for significant level alpha and the horizontal broken line indicate the homogeneity of the stations (Appendix Figure 1). If the P-value is greater than the alpha value the meteorological station is homogenous, but if the P-value is less than the alpha value during analysis we should refill the missing data of the meteorological stations and redo the testing by the software until it becomes homogenous (Table 8).

Table 8. Homogeneity testing of rainfall data results

Name of Station	Variable	Obs.	Mean	SD	To	alpha	P-Value
Holetta	Prec.	28	972.8	139.796	7.471	0.05	0.051
Addis Alem	Prec.	28	1150.5	443.110	5.617	0.05	0.186
Kimoye	Prec.	28	109.6	90.999	8.231	0.05	0.090

To= static derives, SD= Standard deviation, Prec. = Precipitation, Obs = Observation number

4.1.6. Areal Rainfall distribution

In this study, the Thiessen polygon method was used for determination of the contribution of each meteorological stations, rainfall amount to the watershed and the area coverage each meteorological stations (Figure 13). This method identifies areal weight coverage of each meteorological station to the watershed (Table 9).

Table 9. Theissen polygon Gauge weight of Holetta watershed

S.NO	Rainfall stations	Area weight (km^2)	Gauge weight (%)
1	Holetta	216.5	52%
2	Addis Alem	116.25	28%
3	Kimoye	83.02	20%

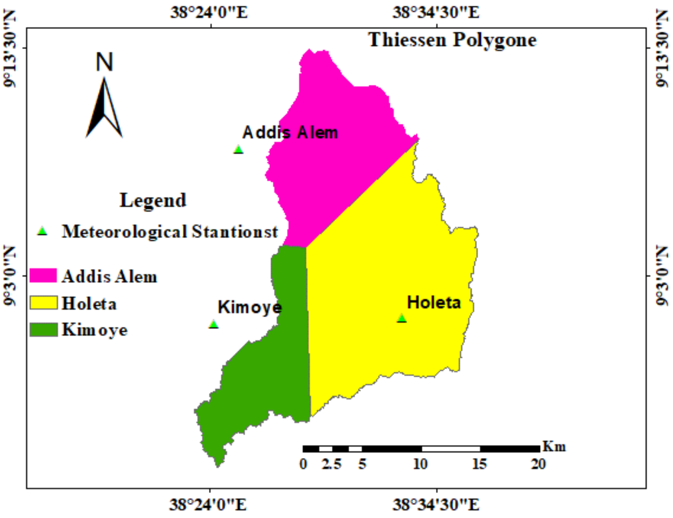

Figure 13. Thiessen polygon developed for Holetta watershed

4.1.7. Land use classification of the watershed

There are six land use /land cover types recognized from the land use map of Holetta watershed (Figure 14). The agricultural land, at which agriculture practice takes places, is the dominant land-use type in the watershed which comprises 25.1% of the total watershed area. Bare land and pasture land covers 18.8% and 21.7% of the total watershed area respectively. The Forest coverage is 2.6% of the total watershed area. Settlement and

Grassland are found in small land coverage with an area of 19.87% and 11.93% respectively (Appendix Table 6).

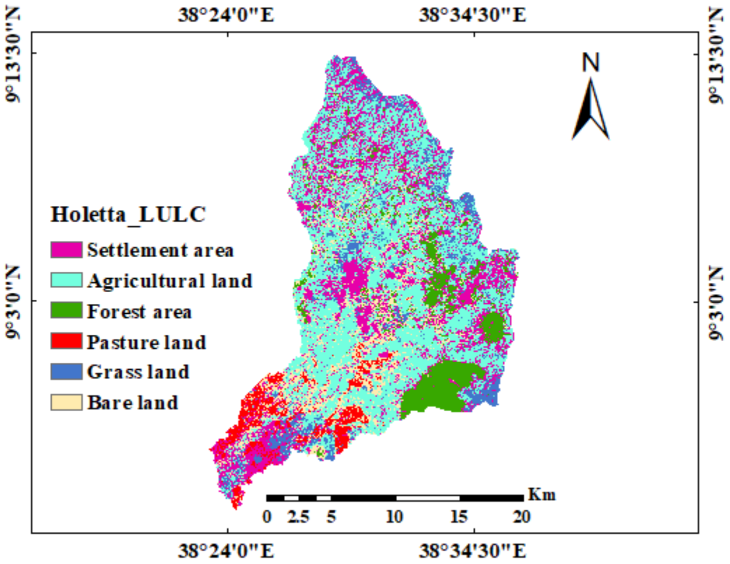

Figure 5. Land use land cover of the study area

4.1.8. Groundwater depth

For this study, the groundwater depth grid map (Figure 15) was produced by using 25 well data that present in the watershed and in the vicinity of the watershed (Appendix Table 7 and Appendix Figure 5). The annual minimum groundwater depth is 21.55 m and the maximum depth is 50 m with a mean and standard deviation value of 27.67 m and 2.77 m respectively.

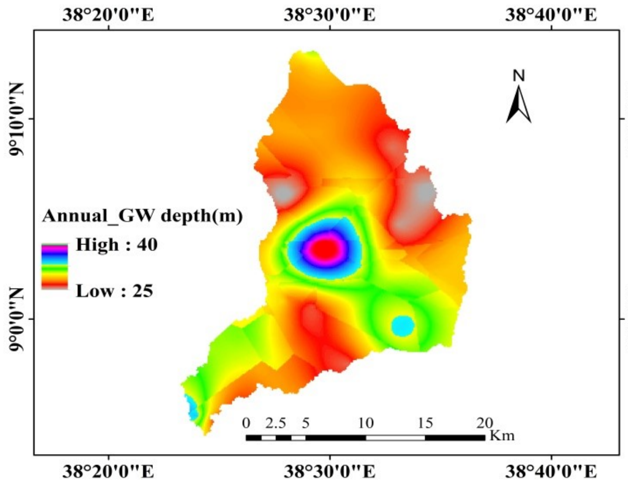

Figure 6. Annual groundwater depth grid map

4.1.9. Wind speed

The mean annual wind speed of the study area is 1.8 m/s. The winter and summer wind speeds were 1.9 m/s and 1.2 m/s respectively (figure 16). It is recorded at 2 meters above the ground surface.

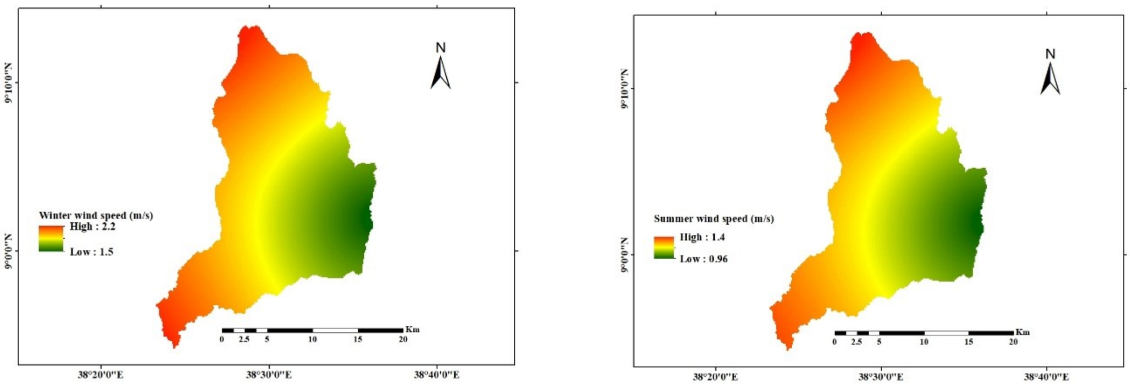

Figure 7. The average winter and summer wind speed of Holetta Wtershed

4.1.10. Rainfall

The grid maps of annual, summer and winter Rainfall of Holetta Watershed is given by (Figure 17 and 18) respectively. The average 28 years annual Rainfall was 1,035 mm the amounts of precipitation high at northern parts of the watershed. More than 68% of the rain occurs during the rainy season.

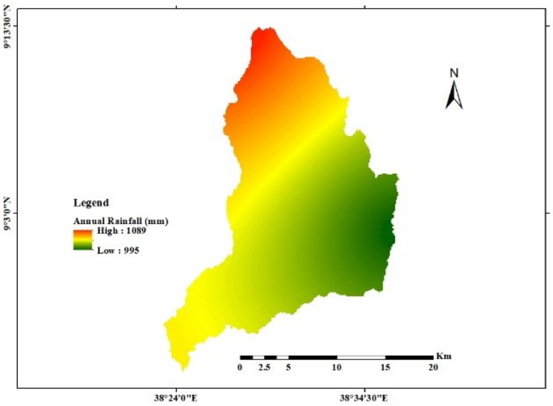

Figure 8. Annual rainfall gird map of Holetta Watershed

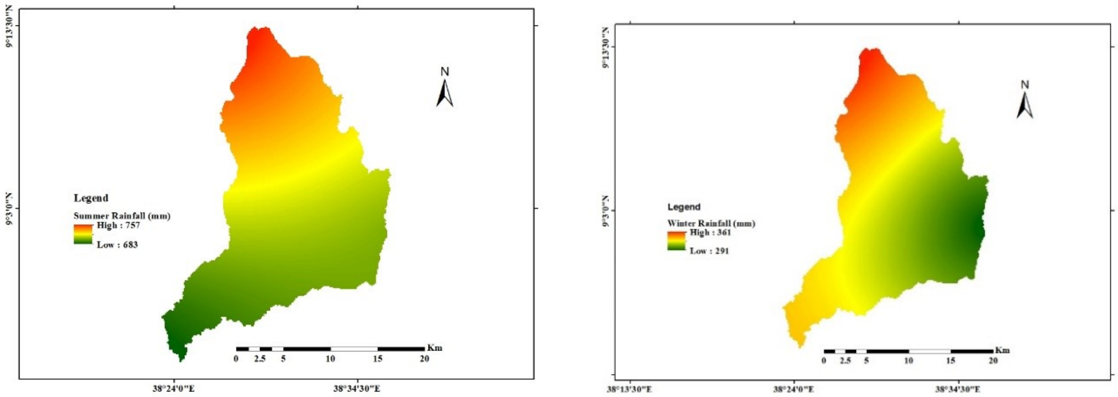

Figure 9. Grid map of summer and wintet rainfall of Holetta watershed

4.1.11. Mean Temperature

The grid maps of summer and winter mean temperature of Holetta watershed is given by figure 19 below. The average summer and winter mean temperature of the watershed are 17.56 °C and 14.6 °C respectively. The average annual temperature of the watershed was 16.5 °C.

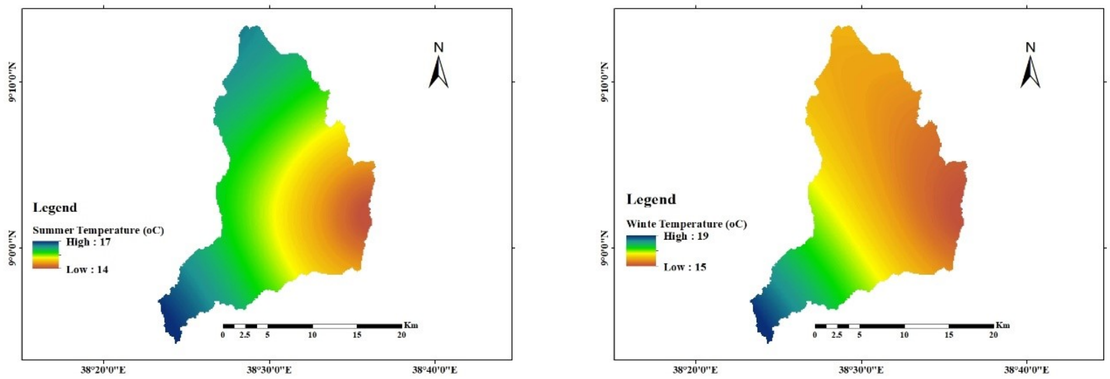

Figure 10. Grid map of summer and winter mean temperature of Holetta watershed

4.1.12. Potential evapotranspiration

Evapotranspiration grid map of the watershed is given by Figure 20 below. The averages of summer and winter evapotranspiration of the watershed are 1115 mm/year and 1711 mm/year respectively.

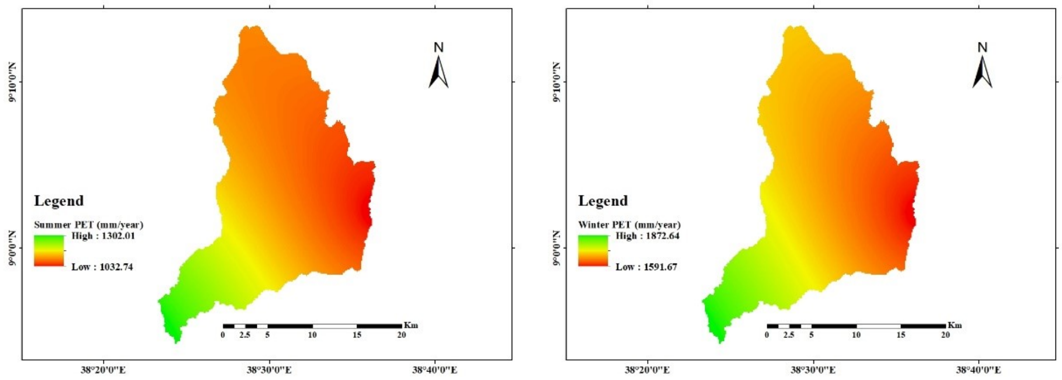

Figure 11. Grid map of summer and winter average PET of Holetta watershed

4.2. Water Balance Analysis by WetSpass

The WetSpass model results consist of several monthly hydrologic outputs. The major outputs are the digital maps of monthly groundwater recharge, surface runoff, actual evapotranspiration and interception. These maps are raster-shaped, in which every pixel represents the magnitude of the respective component of water balance, expressed as layer thickness (in mm). All of the grid cells have 209 and 301 number rows and columns respectively. To make equal columns and rows for the grid cells clip them with each other's. The actual evapotranspiration per pixel is calculated by WetSpass as a sum of evaporation from bare soil, open water and impervious surface area, summation of transpiration and interception of vegetated area (Abdollahi *et al.*, 2017).

4.2.1. Groundwater Recharge

Water budgets are fundamental components of any conceptual models of a hydrologic system, providing a link between recharge processes and other processes in the hydrologic cycle (Healy *et al.,* 2010). Water balance represents the hydrological gains and losses of a given system. In this study, WetSpass model was applied and all water balance computations were carried out from model output as described in the next section of this paper.

The WetSpass model determines the long term average spatially distributed recharge seasonally and annually as a spatial variable dependent on the soil texture, land use, slope, and meteorological conditions (Zarei *et al.,* 2016; Tesfamichael *et al.,* 2013; Negash, 2017; Abdollahi *et al.*, 2017; Esayas and Gebeyehu, 2018). The calculated groundwater recharge from the watershed by WetSpass was range from 32 mm to 195 mm for the summer and zero to 137 mm for the winter season (Figure 21 and 22) respectively. The average summer and winter value of recharge was 104mm and 5 mm respectively. The standard deviations of both summer and winter were 35 mm and 15.4 mm. The average annual value of this watershed recharge was estimated to be 109.45 mm/year, which is about 10.6% of the mean annual precipitation (1,035 mm). About 95% of the annual groundwater recharge of the watershed occurs during the wet season (summer), and the remaining 5% in the dry season (winter). The groundwater recharge potential was highly variable from season to season this high variation occurs due to variation in amounts of precipitation. The average annual groundwater recharge of Holetta watershed was estimated to be 45.5 million meter cubic per year in the total watershed area.

In the study conducted on groundwater recharge potential of Modjo sub-basin upper Awash, by using WetSpass model annual groundwater recharge was estimated as 83 mm/year which was estimated as 8.9% of the annual precipitation of the basin (Negash, 2017). Similarly, the annual groundwater recharge of Koka and Becho areas which was estimated by base flow separation (BFS) methods was estimated to be 111 mm/year, this accounts for 12.1% the annual groundwater recharge of the basin (Alemu, 2017), Esayas and Gebeyehu (2018) estimate groundwater recharge for Birki watershed, the eastern zone of Tigray, Northern Ethiopia was 24.9 mm/year. This contributes to 7.4% as recharge to groundwater. Almost similar to this study result; therefore, we can conclude that the WetSpass model simulates the recharge effectively for Holetta watershed.

The groundwater recharge was fairly distributed in the summer season throughout the watershed; this is due to the existence of precipitation in all parts of the watershed. But the degree of distribution is fluctuating from location to location depending on soil type, rainfall intensity, and infiltration characteristics of the soil, land use and slope. The summer recharge was low at steep slope areas; because around the steep slope, the precipitation easily converted to surface runoff. In the winter season, groundwater recharge was very high in low land areas the watershed (Figure 22).

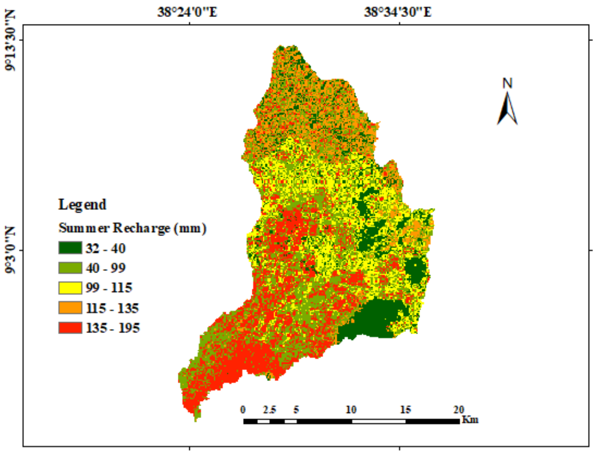

Figure 12. Simulated summer groundwater recharge of Holetta Watershed with WetSpass

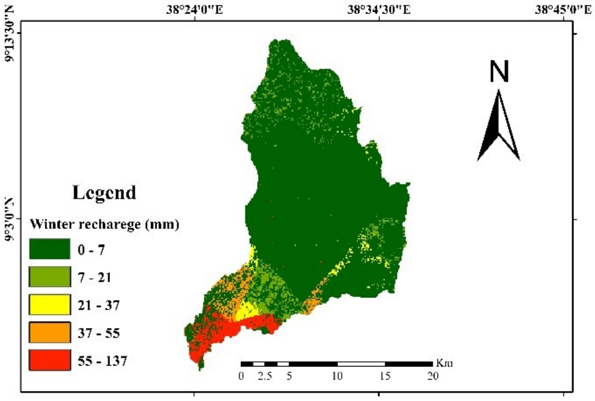

Figure 13. Simulated winter groundwater recharge of Holetta Watershed with WetSpass

4.2.2. Evapotranspiration

Evapotranspiration (ETo) can be defined as the transfer of water in the form of water vapor from the soil surface, a body of water, and vegetative and other surfaces to the atmosphere. Evapotranspiration in agro-ecosystems is the sum of two terms; evaporation, in which water evaporates from soil, water surfaces, or from plant leaf surfaces holding water droplets from rain, irrigation, or dew formation and transpiration, in which water entering the plant roots is carried to stems and leaves for building plant tissue via photosynthesis and then passed through the leaves of the plant into the atmosphere (Wane *et al., 2014).*

It is an influential factor in the estimation of water balance analysis. As explained in chapter 2, WetSpass approach aims at describing the evapotranspiration process in a physically based way. The 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 (Abdollahi *et al.*, 2017).

The simulated annual minimum and maximum evapotranspiration of Holetta Watershed was 577 mm/year and 962 mm/year respectively, its average annual evapotranspiration was 770 mm/year (Figure 23). It accounts 74.3% of water loss in the watershed. Therefore the total annual losses of precipitation by evapotranspiration become 320 Mm^3/year (10,147 L/s) in this watershed. The average summer and winter evapotranspiration are 575mm and 195mm respectively. This shows that most of the water losses in this watershed are taken through evapotranspiration processes. In this watershed, the annual evapotranspiration was very high in forest areas (in the eastern parts of the watershed), pasturelands areas and agricultural lands. In this watershed evapotranspiration's were high at the highland areas of the watershed this is due to high rainfall, high coverage of grass and forest at the high land areas (Figure 23).

The variation of summer and winter evapotranspiration in this watershed was very high, which accounts for 76.8% and 23.2% of the total water losses by evapotranspiration in the watershed respectively. This high difference was due to, high precipitation at summer season which leads to high evaporation and high transpiration from agricultural and grassland areas. In contrast during winter season (dry period), the amounts of precipitation were very little and also the evapotranspiration was to be too low (Figure 24a and b).

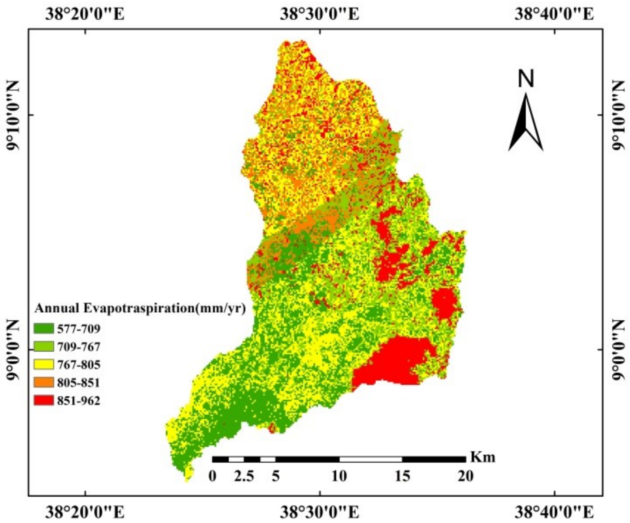

Figure 14. Annual simulated evapotranspiration of Holetta watershed

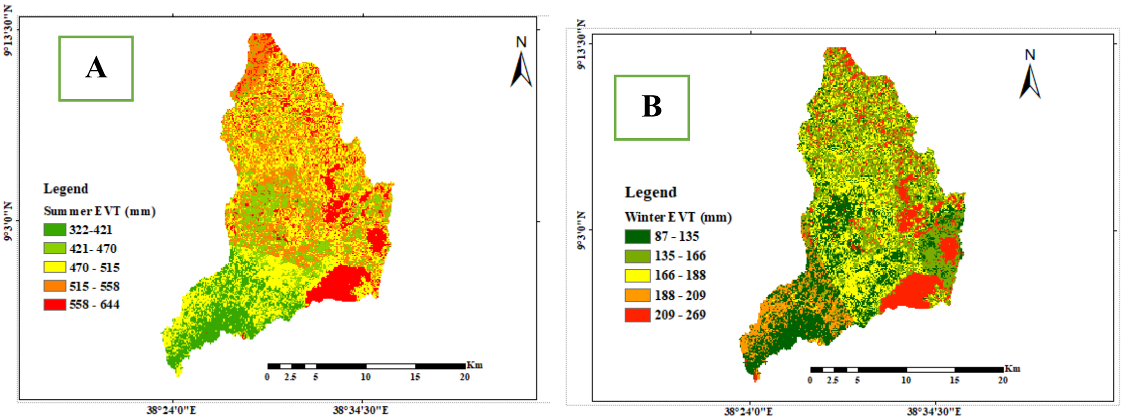

Figure 15. Summer (A) and winter (B) simulated evapotranspiration of Holetta watershed

4.2.3. Surface runoff

Surface Runoff can be described as the part of the water cycle that flows overland as surface water instead of being absorbed into groundwater or evaporating. It is formed when the amounts of precipitation are greater than the infiltration capacity of the soil. It is forms of water loss from the given watershed. To estimate the surface runoff of Holetta watershed WetSpass uses runoff coefficient which varies its value with vegetation type, soil type and slope. The surface runoff of Holetta watershed shows variation with land-use, soil type, slope, topography, precipitation and the other meteorological parameters.

The amount of surface runoff also shows variation in summer and winter season. The annual surface runoff in the Holetta watershed ranges from 100mm/year to 350 mm/year. The mean value represents 157 mm/year (2,070 l/s); it accounts 15.1% of the annual precipitation loss in the watershed. From this, about 77% of the surface runoff occurs during the wet months (June to September) while the remaining 23% occurs during the dry months (October to May). This variation comes from rainfall difference in the two seasons. That means the amounts of precipitation is high during the summer season and low during the winter season, which leads to high runoff at summer and low runoff at winter season. Because runoff have direct relationship with precipitation as the intensity of precipitation increase the amounts runoff also increase.

According to the annually simulated surface runoff of the catchment (Figure 25), the central part of the watershed have highest surface runoff due to the presence of humic nitosols which has a low permeability that enhance surface runoff and also it is urbanized area where the probability for formation of surface runoff is high. On the other hand, the eastern part of the watershed which is covered by forest, southwestern part, southern part which has gentle slope around the outlet, southeastern part and northern part has less surface runoff. This is caused due to high infiltration capacity of soil associated with forest and shrubs coverage of the area which hinders surface runoff formation. This shows these soil types and land use class has great impact on annual surface runoff of Holetta watershed and creates opportunity for the formation of groundwater recharge.

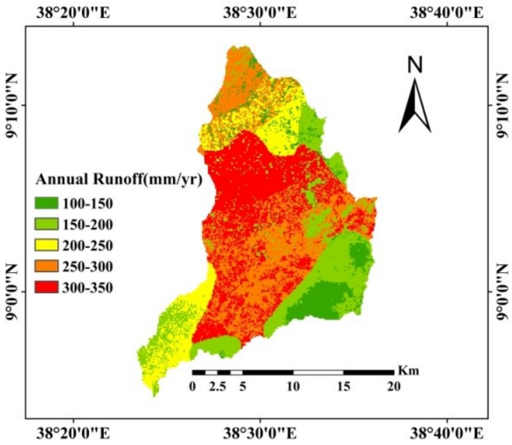

Figure 16. The simulated annual surface runoff of Holetta watershed

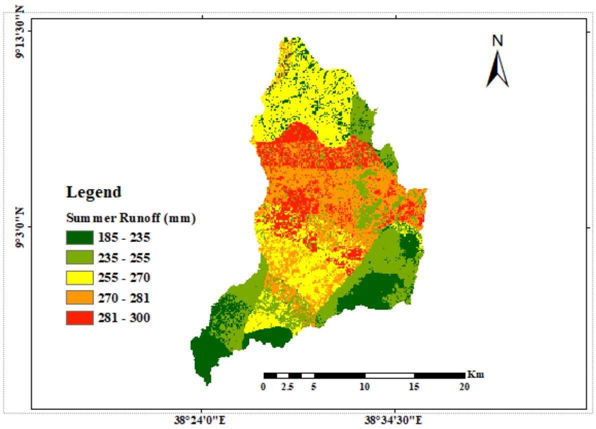

Figure 17. Simulated summer runoff of Holetta Watershed

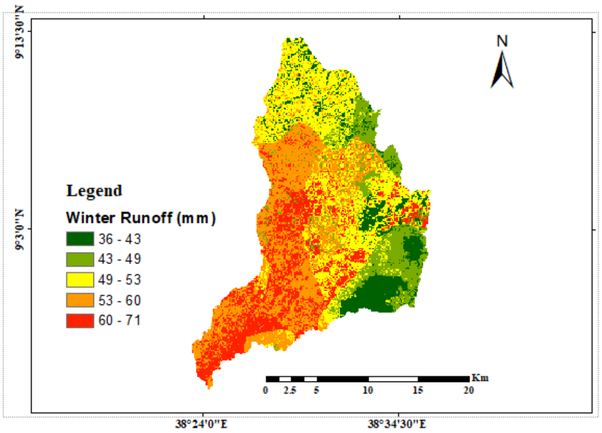

Figure 18. Simulated winter runoff of Holetta Watershed by WetSpass model

According to WetSpass simulated result the annual surface runoff is very high at central parts of the watershed, where the infiltration capacity of the soil is low, which can be used as an opportunity for water harvesting system in this area.

Table 10. Long term annual and seasonal averages of WetSpass simulated results (mm)

Hydrologic components (mm)	Seasonal average		Annual average (mm)
	Summer (mm)	Winter (mm)	
Runoff	120	40	157
Evapotranspiration	575	195	770
Interception	33	24.8	57.8
Transpiration	100	21	121
Soil evaporation	8.6	2.9	11.5
recharge	104	5.45	109.45

4.2.4. Water balance analysis by land use, soil type and slope class

Land-surface topography plays an important role in both diffuse and focused recharge. Steep slopes tend to have low infiltration rates and high runoff rates. Flat land surfaces that have poor surface drainage are more conducive to diffuse recharge; these conditions also favor flooding. Small, often elusive depressions can have an intense influence on infiltration rates. Local relief, orientation, and altitude of mountain ranges are additional topographic factors that can affect recharge processes (Healy *et al.,* 2010).

WetSpass determines the total evapotranspiration as the sum of the evaporation from soil intercepted water and transpiration from vegetated areas; it is automatic that the evapotranspiration varies spatially according to the land-use class, slope and soil types of the watershed. It is very high at grassland area of the watershed where there is low runoff and the infiltration capacity of the soil high; at this time their high amounts of evaporation and transpiration which leads to high evapotranspiration. Also, evapotranspiration is high in low land due to high solar radiation and high wind speed, but it low at settlement area due to high runoff formation (Figure 23).

Table 11. Average water balance in land use difference

No.	Land use class	Average water balance components (mm)			
		precipitation	ET	Runoff	Recharge
1	Agricultural land	1025	700	250	75
2	Settlement area	790	690	160	30
3	Pasture land	1010	880	250	250
4	Bare land	950	735	205	10
5	Grass land	1190	850	130	210
6	Forest area	1250	1000	185	65

4.2.5. Soil evaporation

Soil evaporation is the loss of water from the soil surface by evaporation to the atmosphere. It was very high in bare land areas and settlement areas because it is directly exposed to solar radiation, also such areas have low infiltration rate and it has gentle slope in this watershed due to this problem the precipitated water is highly lost by soil evaporation (Table 12). The annual soil evaporation of Holetta watershed ranges from zero to 54 mmm. The average annual soil evaporation and its standard deviations are 12 mm and 20 mm respectively. The minimum soil evaporation occurs in agricultural land and forest areas (Figure 28).

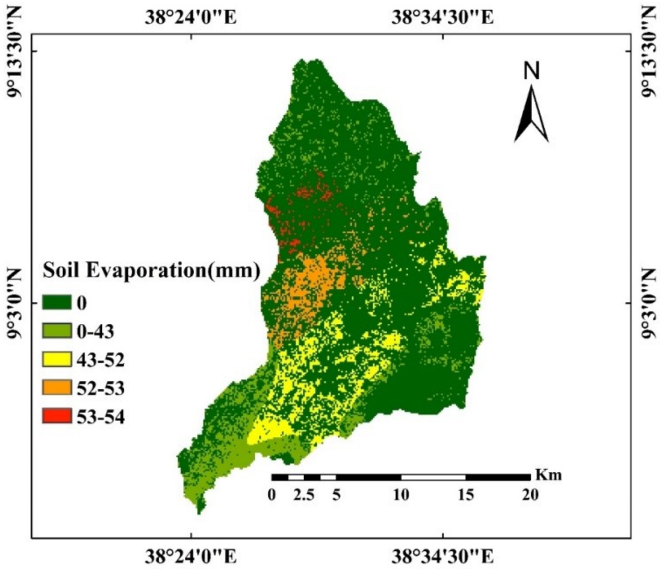

Figure 19. Simulated soil evaporation of Holetta Watershed by WetSpass model

In Northern Ethiopia, Teklebirhan *et al.,* (2012) simulate the water balance components including groundwater recharge, evapotranspiration and surface runoff using WetSpass model. Their study results show that the mean annual groundwater recharge, evapotranspiration and surface runoff were found to be 66 mm, 440 mm and 40 mm respectively. Consequently, 12% of the precipitation becomes recharge while evapotranspiration and surface runoff are 81% and 7% of the precipitation respectively. Tesfamichael *et al.* (2013) used WetSpass model to estimate the availability of surface, and groundwater water resources in the Geba basin. According to the results of WetSpass 76% of the precipitation is lost by evapotranspiration, 18% and 6% of the precipitation becomes surface runoff and groundwater recharge respectively.

Al-Kuisi and El-Naqa (2013) estimating the groundwater recharge in Jafr basin using WetSpass model. They found that the long-term temporal and spatial average annual rainfall of 53.5 mm was distributed as 2.61 mm (4.9%) of surface runoff, 50.6 mm (94.6%) of evapotranspiration, and 0.27 mm (0.5%) of recharge. This recharge corresponds to 3.67 mm for the Jafr basin. Results show that WetSpass is a suitable model to simulate the water balance components for this basin. Also Aish (2014) used WetSpass model in the Gaza Strip to estimate the water balance components. His study shows that 77% of precipitation is lost through evapotranspiration, 11% becomes surface runoff and 12 % of precipitation recharges the groundwater system. In general the simulated result of Holetta watershed by WetSpass model is almost similar to results of different authors in different parts of Ethiopia and the world.

Table 12. The water balance component in different soil types

No.	Soil type	Average water balance components (mm)			
		Precipitation	ET	Runoff	Recharge
1	Humic-Nitosols	1409	850	514	45
2	Chromic-Luvisols	1500	1155	180	165
3	Eutric-Vertisols	650	575	15	50
4	Vertic-Cambisols	581	385	81	115

4.3. Analysis of crop water requirement

4.3.1. Effective rainfall

Rainfall estimates are paramount importance since utilization of rainfall would facilitate assured crop production. A precise estimate of the quantity of rainfall that is useful over a period of time could provide a general picture regarding its supplemental role on irrigation (Wane *et al., 2014).* Effective rainfall is influenced by factors such as quantity and intensity of rainfall, evapotranspiration and percolation losses; crop and irrigation management practices. Estimates of effective rainfall are extremely useful for operation planning and management issues including determine optimal cropping pattern; determining optimal operational policies for irrigation systems; design of drainage systems and real-time control (Wane *et al., 2014).*

Effective Precipitation (EP) is the amount of precipitation that is actually added and stored in the soil. Effective precipitation enters the soil and becomes available to the plant. The moisture deficit is calculated by subtracting the effective precipitation from the calculated evapotranspiration. The total effective precipitation was 32.1 mm in this study area during the total period of the plant (Appendix Table 12). The monthly rainfall and effective rainfall of the watershed at Holetta station is shown on Figure 29.

4.3.2. Crop water requirement

Crop water requirement is the total amounts of water needed for normal growth, development and yield of crop thought-out its growing period. The source of water for CWR may be supplied by precipitation or by irrigation or by both. The water requirement of a crop is dependent upon, crop factors (like variety, growth stage, duration, plant population and growing season), soil factors (like texture, structure, depth, and topography), climatic factors (like temperature, relative humidity and wind speed) and crop management practices like tillage, fertilization, weeding etc.(Allen *et al.*, 2005).

All calculation procedures used in CropWat 8.0 are based on the FAO Irrigation and Drainage paper 56 (FAO, 1998) in this study. The crop water requirement (CWR) and irrigation requirement (IR) of potato throughout the entire growing period of the study are summarized in table 13. The monthly crop water requirements are 42.3, 94.8, 170.3, 141.8 and 33.8 mm for January, February, March, April and May respectively (Table 13). The crop water requirement was rise through the crop stages i.e. from initial stage to mid-season and decline at late season or harvesting season (Figure 30).

Table 13. Estimated irrigation water requirement (mm/month) of potato crop in the watershed

Month	ETc (mm/month)	Irrigation requirement (mm/month)
Jan	42.3	42.3
Feb	94.8	94.7
Mar	170.3	161.8
Apr	141.8	127.2
May	33.8	25
Total	483.2	451.2

4.3.3. Irrigation requirement

An irrigation requirement is the quantity, or depth, of irrigation water in addition to precipitation required to produce the desired crop yield and quality and to maintain an acceptable salt balance in the root zone. The total irrigation requirement of potato crop in this watershed was estimated as 483.2 mm/seasons of the crop. The monthly irrigation requirements are 42.3, 94.7, 161.8, 127.2 and 25 mm for January, February, March, April and May respectively (Table 13). The irrigation requirement was very high in the mid-season (in March) in this watershed because; in this season the Kc of this crop is high, which leads to high irrigation water requirement. In the initial stage and late season of the crop irrigation requirements are low because at those stage the plant does not require high water. At initial the Kc value is small, at the late season the crop is already mature and do not need high water.

The amounts of crop water requirements (ETc) and irrigation requirements in January and February are equal; that means in those month the source of water for the crop growth is only irrigation water. But in March, April and May the crop water requirement was greater than the irrigation requirements of the potato crop; that means there is additional source of water to irrigation to satisfy the crop growth (Figure 30). The total irrigation requirement of potato in the study area for total growing period and area is give on appendix table 12.

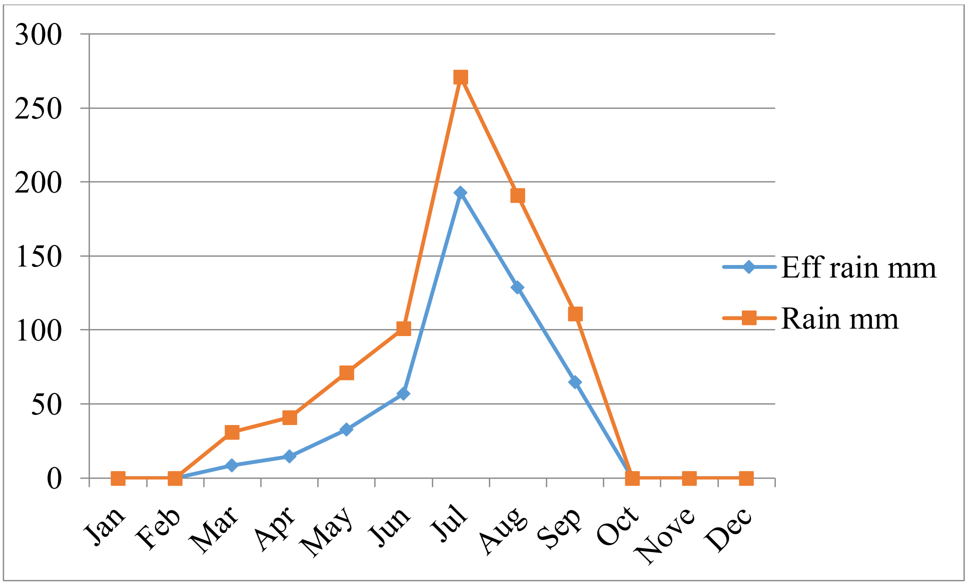

Figure 20. Monthly Rainfall VS effective rainfall calculated by CropWat 8.0 model

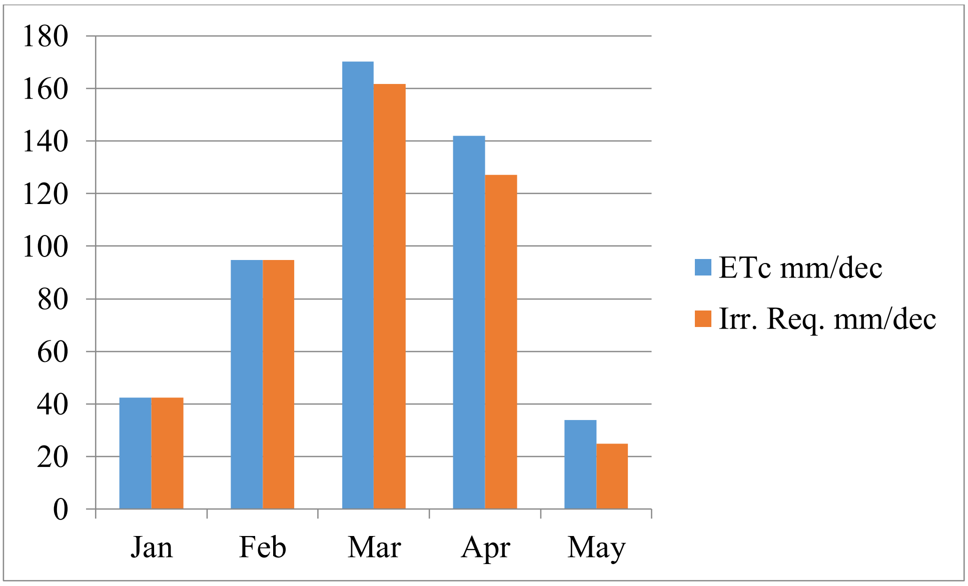

Figure 21. Irrigation and crop water requirement of potato crop simulated by CropWat8.0

4.3.4. Actual irrigation requirement

Actual irrigation requirement is the difference between actual water used by the crop and the amounts of effective rainfall during the season of the crop. The actual water used by potato crop and effective rainfall during the period of this crop was 479.4 and 64.1 mm respectively. Therefore; the actual irrigation requirement of potato in the study area will be 415.3 mm (Table 14).

Table 14 Estimation of total crop water requirement and Net irrigation requirement

No	Crop	Crop water requirement (mm)	Effective rainfall (mm)	Irrigation Requirement (mm)	Actual Irrigation Requirement (mm)
1	potato	483.2	77.2	451.1	415.3

4.4. The Contribution of Holetta River for Irrigation in the Area

The Holetta River is a tributary of Awash River, which joins it after travelling about 25 km downstream of the gauging station. It is Perennial River and the main source of surface water in the study area. The river was gauged since 1975 and for this study, the 1994 - 2009 time series of the river discharge data was used. The average annual river flow at Holetta River was 45.7 million cubic meters (MCM). The flow was low from January to

May and it started to increase at June. The peak flow was 17.61 MCM, which occurred in August, and the minimum flow was 0.70 MCM in February (Appendix Table 10).

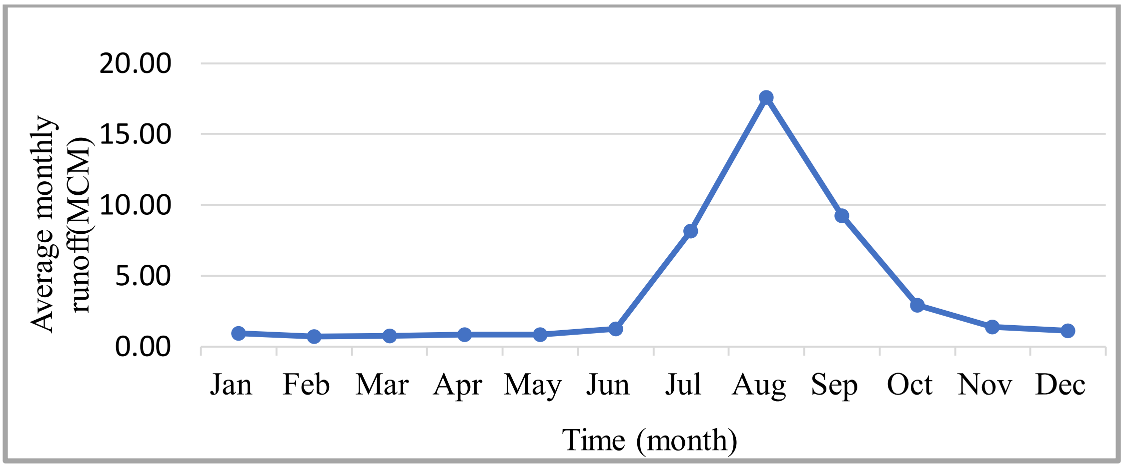

Figure 22. Average monthly runoff of Holetta River at the gauge station (1994-2009)

The volume of water discharge in this river decrease during dry period, in contrast the water demands in this watershed highly increase during the dry season. Especially the demand for irrigation, domestic and livestock rise. As discussed in last section of this paper the irrigation requirement was very high starting from January to May, in opposite of this the major source surface water in this watershed is declined starting from January to May (Figure 31).

As shown on Figure 22 the groundwater recharge is very low at the central parts of the watershed, to overcome this problem water harvesting practice should be done to harvest the excess discharge during the summer season and use the harvested water as supplementary source of irrigation and livestock consumption. Also by using groundwater in the watershed can reduce conflict on surface water resource when water demand increase. According WetSpass simulation results there is high groundwater recharge at the downstream of Holetta watershed. Therefore, the societies who leave in the downstream of the watershed can use groundwater for irrigation, livestock consumption and domestic uses.

5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1. Summary and Conclusions

Water resource is a crucial element for life, so as to maximize its use, proper planning, management, and wise utilization is crucial in the twenty-first century. To do so, the development and application of GIS and remote-sensing techniques make the assessment and modeling of water resources easy and effective for such a purpose. The WetSpass model which is a simulation model for groundwater recharge is based on biophysical and hydro-meteorological properties and it is important to estimate long-term annual average groundwater recharge in seasonal and annual basis for wise utilization, proper management and future planning of water resources (Esayas and Gebeyew, 2018).

The overall objective of this thesis work was to estimate spatial groundwater potential, average long term seasonal groundwater recharge by using WetSpass model, and to estimate the crop water requirement of potato crop produced by irrigation in Holetta watershed using CropWat 8.0 model. A spatially distributed WetSpass model was used to estimate annual and seasonal long term groundwater recharge and CropWat 8.0 was used to estimate the irrigation and crop water requirements of potato in the study area.

The model results show that all the water balance components are dependent on the soil type, land use classes and elevation difference. In this study, GIS and remote sensing techniques has been applied to develop the land use map of the watershed through supervised classification processes by using ArcMap 10.4.

The model results show that the mean annual evapotranspiration in the watershed is about 770 mm/year, which is about 74.3% of the mean annual precipitation. Thus an average of 320 Mm^3 of evapotranspiration will be loosed per year or 10,174 l/s from the total area of Holetta Watershed (415.7km^2).

The simulated annual surface runoff of Holetta watershed was range from 100mm/year to 350mm/year, the average annual surface runoff was 157 mm/year (2,070 l/s), and it accounts 15.1% of the annual precipitation loss in the watershed. The surface runoff is high in summer season on bare land and settlement areas in general.

The simulated average annual ground water recharge value of this watershed was estimated to be 109.45 mm/year (1,443 l/s), which is about 10.6% of the mean annual precipitation the total watershed (1,035 mm). Therefore; the annual average ground water recharge volume of the watershed was 45.5 million meter cubic. About 95% of the annual groundwater recharge of the watershed occurs summer season, and the remaining 5% in winter season. I.e. the average summer and winter value of recharge was 104mm and 5mm respectively.

The calculated crop water requirements and irrigation requirements of potato crop in Holetta watershed are 483.1mm and 451.1mm respectively. The monthly irrigation requirements are 42.3, 94.7, 161.8, 127.2 and 25 mm for Jan, Feb, Mar, Apr and May respectively and the monthly crop water requirements for full growing period of this crop is calculated are: The monthly crop water requirements are 42.3, 94.8, 170.3, 141.8 and 33.8 mm for Jan, Feb, Mar, Apr and May respectively. It is clearly show that the crop water requirement of the crop was high at development stage and mid-season.

5.2. Recommendation

- ✓ The water balance results obtained from this modeling can be used for future groundwater resources development and improvement of the watershed in particular, for soil and water conservation work, for development of irrigation scheme.
- ✓ The groundwater recharge in this watershed is estimated as 45.5 MCM/year; this huge amounts of water can satisfies the demand of water in the watershed, if it is properly used.
- ✓ In this watershed there is huge volume of runoff which, accounts 65Mm^3 if this huge amounts of water is properly harvest as flood water, it can be additional source of water for irrigation during water shortage season.
- ✓ The parameter values embedded in the currently existing model are basically prepared for the realities and conditions of temperate regions which might need to be modified for the actual situations and conditions of the study area. However, a further study could be needed to further fine the land use, soil as well as runoff coefficient parameter tables of the study area.
- ✓ This study depends only on the hydro-meteorological data and special pattern of the watershed to understand spatial and temporal groundwater recharge, further study should

be investigated including geological and aquifer property for more understanding of groundwater dynamics in the catchment for better groundwater resource development and management.

- ✓ Water harvesting structures required to harvest excess floods occurred at summer season to prevent overflow of Awash River at the downstream.

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7. Appendix

Appendix Table 1. The average monthly, Annual, summer and winter precipitation of all stations (mm)

No	Stations Name	Jan	Feb	Mar	Apr	Ma	Jun	Jul	Ague	Sep	Oct	No	Dec	Winter	Summer	Annual
1	Holetta	19	38	51	70	62	107	224	235	137	21	9	20	290	703	993
2	Addis Alem	18	33	67	67	86	147	263	231	128	26	26	14	337	769	1106
3	Kimoye	16	37	67	73	75	134	230	204	105	27	41	36	372	673	1045
4	Average	17.7	36	61.7	70	74.3	129.3	239	223.3	123.3	24.7	25.3	23.3	333	715	1048

Appendix Table 2. The average monthly, annual, summer and winter mean temperature of all stations (°C)

No	Stations	Jan	Feb	Mar	Apr	Ma	Jun	Jul	Ague	Sep	Oct	No	Dec	Winter	Summer	Annual
1	Holetta	13.5	14.5	15.5	16	16.5	15.5	14.5	14.5	14.5	14	13.5	13	14.6	14.75	14.6
2	Addis Alem	16	17.5	18.5	18	18.5	18	16.5	16	16.5	17	16.5	17	17.4	16.75	17.2
3	Kimoye	17	17.5	19	19.5	19.5	18.5	17	17	17	17	16.5	17	17.9	17.375	17.7
4	Average	15.5	16.5	17.7	17.8	18.2	17.3	16.0	15.8	16.0	16.0	15.5	15.7	16.6	16.3	16.5

Appendix Table 3. Average monthly, annual, summer and winter sunshine hour (hours/day)

No	Stations	Jan	Feb	Mar	Apr	Ma	Jun	Jul	Ague	Sep	Oct	No	Dec	Winter	Summer	Annual
1	Holetta	8.9	8.6	8.2	7.2	6.2	4.9	2.7	2.8	4.3	7.6	8.5	8.7	8.0	3.7	6.6
2	Addis Alem	8.8	8.5	7.5	6.7	7.0	5.2	2.9	2.8	4.4	6.9	8.9	8.9	7.9	3.8	6.5
3	Kimoye	10.2	11.7	12.0	12.2	12.1	8.1	2.5	4.0	10.9	12.4	12.1	11.1	11.7	6.4	9.9
4	Average	9.3	9.6	9.2	8.7	8.4	6.1	2.7	3.2	6.5	9.0	9.8	9.6	9.2	4.6	7.7

Appendix Table 4. Mean monthly, yearly, summer and winter wind speeds of all stations (m/s)

No	Stations Name	Jan	Feb	Mar	Apr	Ma	Jun	Jul	Ague	Sep	Oct	No	Dec	Winter	Summer	Annual
1	Holetta	1.4	1.5	1.5	1.5	1.4	1.0	1.0	0.8	1.0	1.4	1.5	1.5	1.5	0.95	1.3
2	Addis Alem	2.2	2.3	2.3	2.4	2.1	1.5	1.5	1.3	1.7	2.3	2.3	2.2	2.3	1.5	2.0
3	Kimoye	2.2	2.3	2.3	2.3	2.3	1.5	1.5	1.3	1.5	2.2	2.3	2.3	2.3	1.45	2.0
4	Mean	1.9	2.0	2.0	2.1	1.9	1.3	1.3	1.1	1.4	2.0	2.0	2.0	2.0	1.28	1.8

Appendix Table 5. Average monthly, annual, summer and winter relative humidity of the meteorological stations (%)

No	Stations	Jan	Feb	Mar	Apr	Ma	Jun	Jul	Ague	Sep	Oct	No	Dec	Winter	Summer	Annual
1	Holetta	49	46	51	58	54	74	93	94	83	64	54	50	53	86	64
2	Addis Alem	50	47	52	56	54	78	90	88	74	59	54	50	53	83	63
3	Kimoye	51	46	50	57	52	70	88	90	79	62	54	52	53	82	63
4	Mean	50	46	51	57	53	74	90	91	79	62	54	51	53	84	63

Appendix Table 6. Summary of land use and soils of Holetta watershed

No	Land use class	Area (km²⁾	Percent of total area (%)	Soil type	Area (km²⁾	Percent of total area (%)
1	Agricultural land	104.3	25.1	Chromic- Luvisols	141.46	34.03
2	Settlement area	82.6	19.87	Humic-Nitosols	215.79	51.91
3	forest	10.8	2.6	Vertic-Cambisols	15. 9	3.82
4	Pasture land	90.21	21.7	Eutric-Vertisols	42.5	10.21
5	grassland	11.93	49.6			
6	Bare land	18.8	78.2			

Appendix Table 7. Wells data in the watershed and around the watershed

No	Well Name	Longitude (°)	Latitude(°)	Elevation(m)	Depth(m)	Static Water Level(m)	Dynamic Water Level(m)	Well Discharge
1	Dewa_Lafto	38.48	9.00	2240	80	30	35	3
2	W/Horbu	38.49	9.01	2242	56	26.5	28.6	4.99
3	Sokuru awaso#2	38.54	9.18	2689	115	32	40	5
4	Haro Boke	38.49	9.22	2659	90	47	52	2.88
5	Bakaka Kore Odo	38.47	9.10	2525	60	21.5	24	3.5
6	Wetabecha Monjoro	38.58	9.11	2676	60	23	27	4.5
7	Ade Simbrite Kotu	38.56	9.12	2704	57	30	36	2.5
8	Wolmera Choke	38.55	9.08	2628	85	24	32	3.3
9	Sokoru Awaso#1	38.55	9.14	2695	99	27	33	5.7
10	Ade Simbrite Kotu#2	38.62	9.14	2689	105	24	29	6.5
11	Nano Suba#1	38.49	8.95	2233	125	31	34	2.3
12	Fole Tulu Rada	38.41	8.92	2066	87	20.66	25	2
13	Nano Suba#2	38.51	8.96	2233	85	25	27	1.55
14	Gaba Robi	38.42	9.13	2568	61	30	45	4
15	Gole Liban	38.38	8.89	2080	125	45	65	3.5
16	Berfta tekofa	38.55	8.99	2750	135	50	77	11
17	Ulafoyata	38.48	9.21	3310	82	33.75	42	8.5
18	Amero	38.40	8.92	2065	155	65	81	5.85
19	Holetta Town	38.50	9.06	2325	200	85	97	12
20	Elala Gojo	38.53	9.10	2257	84	45	52	3.5
21	Kusaye	38.47	9.02	2295	94	47	55	4
22	Berifta lamafa	38.56	9.00	2310	125	49	57	2.5
23	Wajetu Haribo	38.47	9.02	2235	77	27	31	1.57
24	Wajetu Wato Dalecha	38.43	8.93	2115	89	31	35	2
25	Dawa Filafito	38.47	8.98	2215	95	33	40	3.5

Appendix Table 8. The average monthly precipitation and 80% probability accidence of Holetta Station

Year	Jan.	Feb	Mar	Apr	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov	Dec.
1987	3	101	131	138	159	104	177	273	170	28	5	76
1988	32	81	22	107	25	103	264	319	240	32	0	24
1989	20	156	78	70	8	70	247	273	118	3	6	187
1990	29	183	95	98	56	140	251	350	155	25	4	89
1991	21	75	118	21	45	87	243	193	152	3	12	6
1992	26	55	57	97	35	101	202	299	145	36	1	78
1993	18	84	4	133	60	98	213	288	225	29	0	0
1994	0	2	87	46	26	103	225	196	154	0	37	0
1995	0	85	42	124	82	82	206	263	83	16	0	14
1996	88	9	96	66	57	194	220	267	127	9	0	2
1997	14	0	21	95	9	142	236	202	44	54	24	2
1998	58	42	28	66	77	134	298	287	181	69	1	0
1999	76	5	37	8	63	100	264	317	91	65	0	0
2000	0	0	14	79	96	88	173	254	128	32	41	32
2001	8	11	130	37	100	185	274	208	110	27	0	0
2002	73	26	58	38	49	114	282	194	79	0	0	6
2003	18	11	33	47	45	90	166	135	113	15	0	8
2004	6	8	39	153	33	107	212	218	131	4	5	0
2005	22	5	63	67	91	67	292	191	135	32	0	0
2006	0	9	67	101	98	104	295	226	144	13	0	1
2007	0	14	61	36	74	253	141	265	90	21	0	0
2008	0	19	1	31	81	92	288	145	210	40	67	4
2009	20	9	0	30	11	64	210	218	98	16	6	39
2010	0	40	84	65	77	93	272	241	192	0	24	17
2011	0	39	43	32	74	150	257	272	168	0	17	0

2012	0	0	4	99	44	56	275	180	252	13	0	6
2013	0	0	23	121	56	113	89	202	107	22	0	0
2014	21	21	31	36	94	57	149	190	70	10	3	0
2015	7	7	20	0	78	27	74	160	64	0	0	0
Average	**19**	**38**	**51**	**70**	**62**	**107**	**224**	**235**	**137**	**21**	**9**	**20**
80% probability of accidence	0	0	31	41	71	101	271	191	111	0	0	0

Appendix Table 9. Total irrigation requirements of potato during the crop season for total irrigation area (MCM)

No	Irrigation users	Area of irrigated land by Potato crop (ha)	Total Irrigation requirement (MCM)				
			January	February	March	April	May
1	Holetta Agricultural Research center	7	0.003	0.007	0.011	0.009	0.002
2	Tsedey farm	8	0.0032	0.0075	0.013	0.01	0.002
3	Local kebbel farmers	110	0.0465	0.0104	0.18	0.14	0.027
Total		125	0.0527	0.0249	0.204	0.159	0.031

Appendix Table 10. Average monthly runoff (MCM) of Holetta River at gauge station from (1994-2009)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total Annual Runoff (MCM)
1994	0.6	0.43	0.6	0.46	0.47	0.78	8.91	17.15	7.99	1.34	0.63	0.46	39.8
1995	0.38	0.46	0.3	0.43	0.46	0.37	4.31	24.36	13.19	3.01	1.97	1.93	51.2
1996	2.19	1.48	1.32	0.99	1.03	2.11	11.05	28.75	15.27	2.57	1.18	0.95	68.9
1997	0.59	0.37	0.4	0.44	0.38	1.42	4.45	8.45	3.46	0.82	0.45	0.28	21.5
1998	0.81	0.47	0.41	0.42	0.75	0.51	8.27	22.99	17.93	6.41	1.96	1.07	62
1999	0.89	0.56	0.86	0.47	0.48	1.07	8.74	21.91	5.32	4.95	1.02	0.74	47
2000	0.55	0.42	0.35	0.67	1.14	0.57	2.7	12.6	12.03	3	0.98	0.57	35.6
2001	0.43	0.28	0.46	0.39	0.48	1.22	9.83	15.17	5.41	0.93	0.34	0.17	35.1
2002	0.18	0.05	0.12	0.06	0.03	0.24	7.33	8.49	4.59	0.05	0.15	0.02	21.1
2003	1.22	0.92	0.85	1.45	0.86	1.01	7.36	15.1	9.17	2.09	1.01	0.74	41.8
2004	0.79	0.43	0.42	1.37	0.75	1.88	7.27	7.74	6.12	2.07	0.9	0.67	30.4
2005	0.55	0.43	0.62	0.83	1.34	1.4	8.27	15.62	4.64	2.1	0.99	0.64	37.4
2006	0.46	0.34	0.6	0.88	0.76	1.04	8.69	22.76	9.33	2.39	1.28	1.01	49.5
2007	0.88	0.78	0.66	0.83	0.72	1.63	9.1	16.04	4.54	1.79	0.88	0.72	38.6
2008	0.56	0.42	0.29	0.35	0.56	0.92	15.66	24.55	21.3	8.69	5.4	4.39	83.1
2009	4.04	3.35	3.56	3.58	3.5	3.69	8.52	20.07	7.7	4.24	3.24	3.42	68.9
Average	0.95	0.70	0.74	0.85	0.86	1.24	8.15	17.61	9.25	2.90	1.40	1.11	45.74

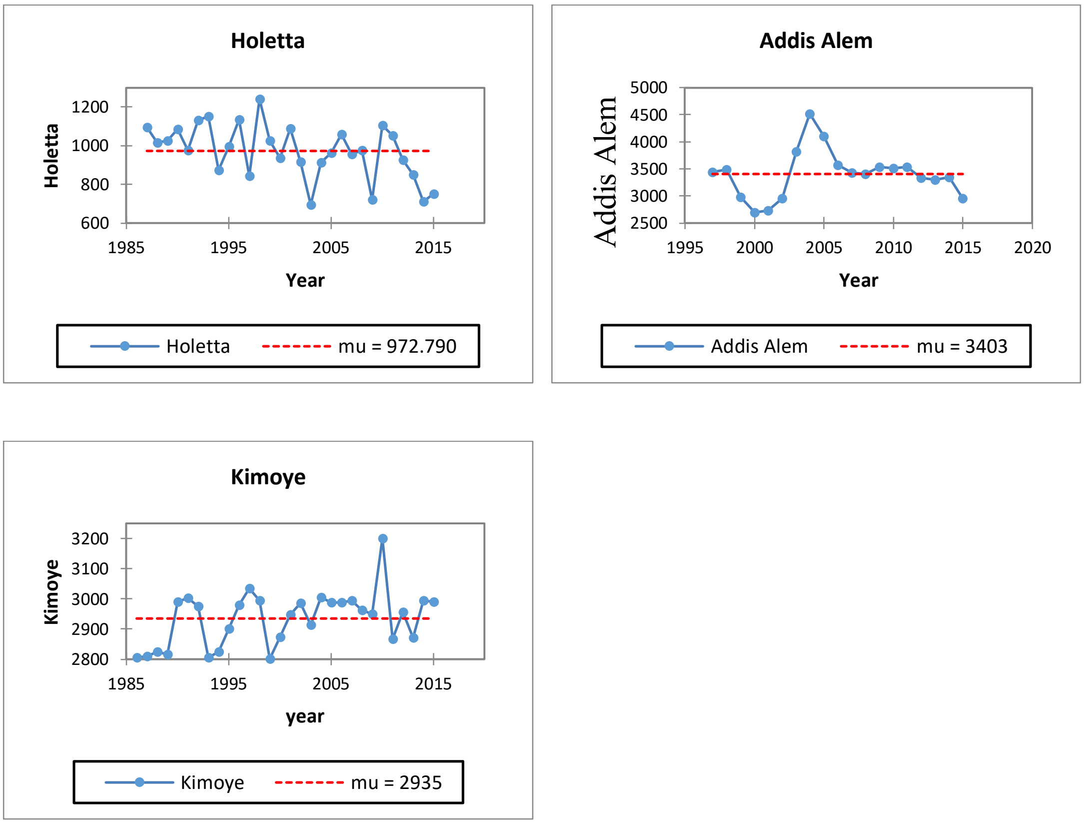
Appendix Table 11. The meteorological data taken from Holetta station to calculate the ETc of Potato by CropWat 8.0

Month	Sunshine hour(hour)	Max Temp(°C)	Min Temp(°C)	Wind speed (km/day)	Relative Humidity (%)	Rain(mm)
Jan	8.9	23	4	186	49	0
Feb	8.6	24	5	197	46	0
Mar	8.2	24	7	195	51	31
Apr	7.2	24	8	202	58	41
May	6.2	25	8	198	54	71
Jun	4.9	23	8	133	74	101
Jul	2.7	20	9	129	93	271
Aug	2.8	20	9	113	84	191
Sep	4.3	21	8	129	83	111
Oct	7.6	22	5	191	64	0
Nov	8.5	23	2	197	54	0
Dec	8.7	23	3	198	50	0

Appendix table 12. Result calculated by CropWat 8.0 models.

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Jan	1	Init	0.45	1.88	1.9	0	1.9
Jan	2	Init	0.45	1.89	18.9	0	18.9
Jan	3	Init	0.45	1.96	21.5	0	21.5
Feb	1	Deve	0.52	2.33	23.3	0	23.3
Feb	2	Deve	0.76	3.51	35.1	0	35.1
Feb	3	Deve	0.98	4.55	36.4	0.1	36.3
Mar	1	Mid	1.16	5.43	54.3	2	52.3
Mar	2	Mid	1.18	5.57	55.7	3	52.8
Mar	3	Mid	1.18	5.48	60.3	3.6	56.7
Apr	1	Late	1.16	5.29	52.9	3.8	49
Apr	2	Late	1.05	4.71	47.1	4.3	42.8
Apr	3	Late	0.94	4.19	41.9	6.5	35.4
May	1	Late	0.83	3.75	33.8	7.9	25
					483.2	31.2	451.1

APPENDIX FIGURES

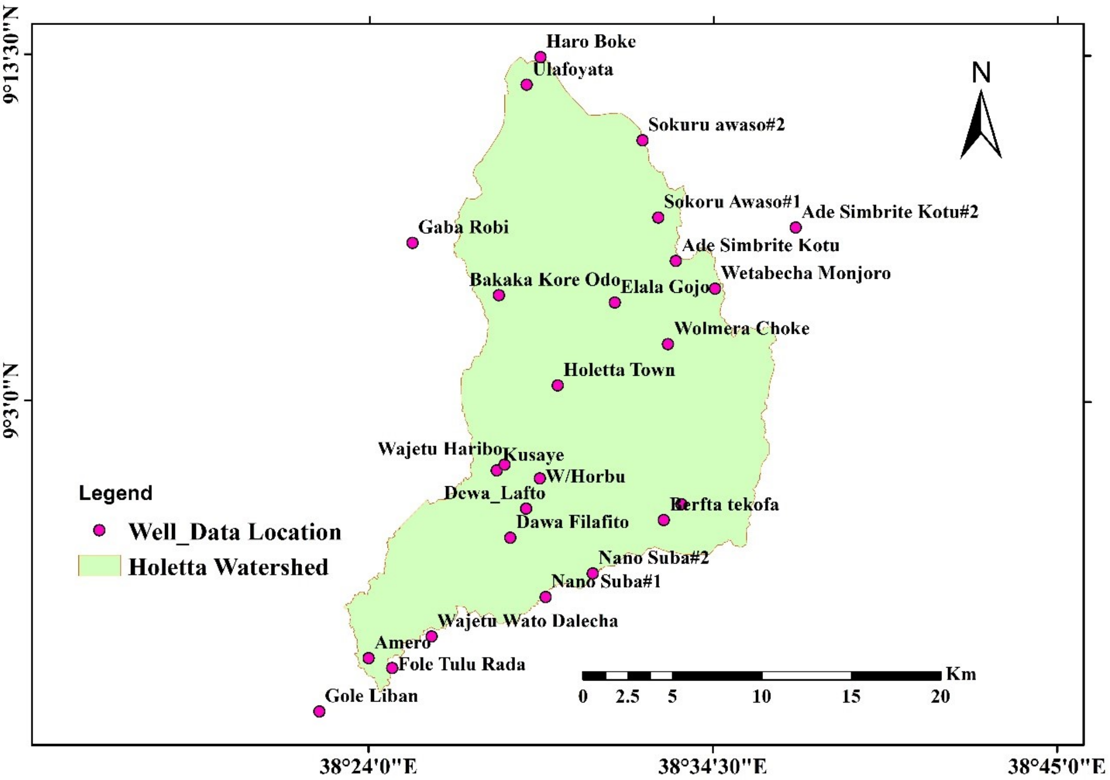


Appendix Figure 1. Homoginity test of the precipitation data of the meteorological stations

Appendix figure 2. Photography taken during soil sample collection by digital camera

Appendix figure 3. Photography taken during measuring of the infiltrations rate by digital camera

Appendix figure 4. Diversion structure of Holetta River



Appendix Figure 5. Well data colected with thire respective location