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Application of Water Balance and SWAT Model for Groundwater Recharge Estimation: Beressa Watershed, Central Ethiopian Plateau, Ethiopia.

Thalada. Suryanarayana[1] Amanuel Godie Gigar[2] Belay Molla Sisay[3]
[1]*Professor of Geology, College of Natural Sciences, Department of Geology, Wollo University, Dessie, Ethiopia.*
[2]*Lecture of Hydrogeology, College of Natural Sciences, Department of Geology, Wollo University, Dessie, Ethiopia.*
[3]*Lectures, Department of Geology, College of Natural Sciences, Debre Birhan University, Debre Birhan, Ethiopia.*
Corresponding Author Name: ***Prof. Suryanarayana Thalada***

ABSTRACT
Recharge is animportant parameter ingroundwaterflow andtransport models. Sustainablegroundwater management also requires knowledge and quantification of groundwater recharge.Quantifyinggroundwaterrechargeisthusaprerequisiteforefficientandsustainablegroundwater resource management. As aquifers are depleted, recharge estimates have becomemore essential in determining appropriate levels of groundwater withdrawal. Water balance andSWATmodelshavebeenappliedtoestimatetheannualgroundwaterrechargeofBeressawatershed, which is part of the Blue Nile Basin in the central Ethiopian highlands. The resultsfrom the water balance method show that from annual precipitation of 947 mm, 641 mm re-evaporates to the atmosphere, 169 mm follows surface runoff and 136 mm percolates through thewater table to the groundwater system. The three water balance components account for 67.66%,17.91% and 14.44% of the annual precipitation, respectively. The result from the SWAT modelshows annual evapotranspiration of 572mm, surface runoff 228mm, interflow 25mm and annualgroundwater recharge of 126 mm. This accounts for 60.42%, 24.12%, 2.69% and 13.35% of theannual precipitation, respectively. The amount of annual sustainable yield is also estimated to be40%ofthe recharge, 17.93 MCM.

Keywords: *Groundwater Resource Management, Water Balance, SWAT Models, Recharge, Watershed,*

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I. INTRODUCTION

1.1 Background

Water is a precious natural resource, without which there would be no life on Earth and itsoccurrenceisthemainfactorwhichmakesourPlanet,TheEarth,veryuniqueinthesolarsystem. Similarly, it constitutes two-thirds of the weight of our body. Our everyday lives dependon the availability of cheap and clean water resources, which are also important for agriculturaland industrial activity (Kevin Hisckok, 2005). Groundwater is water stored in the saturated zonewith in rocks below the water table. Groundwater plays a major role in the livelihood of mankindby providing water for drinking, irrigation, and industrial purposes. Groundwater obtained frombeneath the Earth‟s surface is often cheaper, more convenient and less vulnerable to pollutionthan surface water (Kevin Hisckock, 2005, Saied Eslamain, 2014). Water is the most commonsubstanceonthesurfaceoftheEarth,coveringover70percentoftheplanet.However,about
96.54percentofthetotalamountofwaterisintheoceansandisnotdirectlyusable.Similarly,
1.74 percent of the total water is capped by glaciers and ice caps. This makes Groundwater themost abundant (1.69 %) water resource for direct house hold and other human consumptions ontheplanet (TimDavie,2008).

According to (Freeze and Cherry,1979), groundwater recharge is the entry intothe saturatedzone of water made available at the water-table surface. Recharge is an important parameter ingroundwater flow and transport models. Sustainable groundwater management also requiresknowledgeandquantificationofgroundwaterrecharge.Quantifyinggroundwaterrechargeisthus a prerequisite for efficient and sustainable groundwater resource management. As aquifersare depleted, recharge estimates have become more essential in determining appropriate levels ofgroundwater withdrawal

(KetemaTilahun, 2009).
Beressa watershed is a small watershed locatedwithin the Jema sub-basin of The Blue NileBasin along its South Eastern boundary with the Awash basin. Debre Birhan is the largest cityfoundwithinthewatershed.Thewatershedconstitutesoneoftheregionsinthecountrywithhuge groundwater potential with extensive and highly productive fissured aquifers (T = 10.1 -100m^2/dandQ=5-25l/sforwellsand/orsprings)andextensiveandmoderatelyproductive fissured aquifers (T = 1.1-10 m^2/d and Q = 0.51 - 5 l/s for wells and/or springs) (Jiri Sima, 2018).On the other hand, the watershed is located in a region with huge annual population growth,urbanizationandindustrialization.ZewduAlebachew(2011)hasshowedthatthebuiltupstructures (urbanization) has increased 131% between 1986 and 2000, and 89.7% between 2000and2005aroundDebreBirhanarea.Thisisanannualgrowthrateof 9.38%and17.94%respectively of built-up area for these study years. The study shows the presence of an increasinglarge scaleurbansprawling inthearea.The city isalsobecoming centerofhuge industries,which require largesupply ofwaterresourceand a number ofwater bottling factories. This,along with the increasing urbanization and population increase is expected to exert pressure onthequalityandquantityofgroundwaterresourceswithintheBeressawatershed.Hence,estimation of the annual amount of water being recharged for the aquifers in the watershed is animportant and effective tool for wise utilization and management of the groundwater resource.This study assesses the annual groundwater recharge of the watershed using two techniques,WaterBalance(WB)andSWATmodel.

1.2 LocationandAccessibility

BeressawatershedisfoundincentralEthiopia,withintheNorthShoazoneofAmharaadministrative region around 130 Km North-East of Addis Ababa. Hydrologically, it is foundwithin the Jema sub-basin of Blue Nile Basin along its South-Eastern boundary with the AwashBasin, covering an area of 340Km^2. Administratively, it is found within three Woredas of NorthShoa Zone: AngolelaTera, DebreBirhanZurya and DebreBirhan Town administration (Figure1). Astronomically, the watershed is found between longitude 39.46^o E and 39.73^o E and latitude9.56^o N and 9.75^o N. The watershed is accessible through the main Addis Ababa-Dessie-Mekellemain asphalt road. There are also a number of other roads such as foot trails and dry weatherroads. Large part of the watershed is a flat plateau, which is easily accessible for field studiesexceptsmall areasin theEasternand North-Westerntips, whereitgets rugged.

1.3 Objectives

The main objective of this study is to estimate annual groundwater recharge of the watershedusingWBand SWATmodel.

Specificobjectivesinclude:

- ✓ Tocharacterizetheareaintermsofphysiography,drainage,soilcover,LandUseLandCover(LULC),geologya nd hydrogeology.
- ✓ Toestimateaverageannualwaterbalancecomponents,Precipitation,Evapotranspiration,Runoffand GroundwaterrechargeusingWBandSWATmodel
- ✓ Tocompare groundwaterrechargeestimation usingthetwomethods.
- ✓ Toestimatetheamountofsustainableyieldinthe watershed

1.4 MethodologyandMaterials

The methodology employed to accomplish the objectives set above is principally a desk study ofdifferent data for the given watershed. The watershed is delineated in Arc SWAT interface using30 m resolution SRTM Digital Elevation Model (DEM) data downloaded from open topographywebsite (http://opentopo.sdsc.edu/datasets). The drainage pattern of streams is also extractedsimilarly. The LULC data of the watershed is clipped from Sentinel-2 LULC map of Ethiopia forthe year 2016. (http://geoportal.rcmrd.org/layers/servir%3Aethiopia_sentinel2_lulc2016). On theotherhand,FAOdigitalsoilmapofEthiopiaisusedtocharacterizethesoiltypeofthewatershed(http://www.fao.org/geonetwork/srv/en/metadata.show?id=14116)

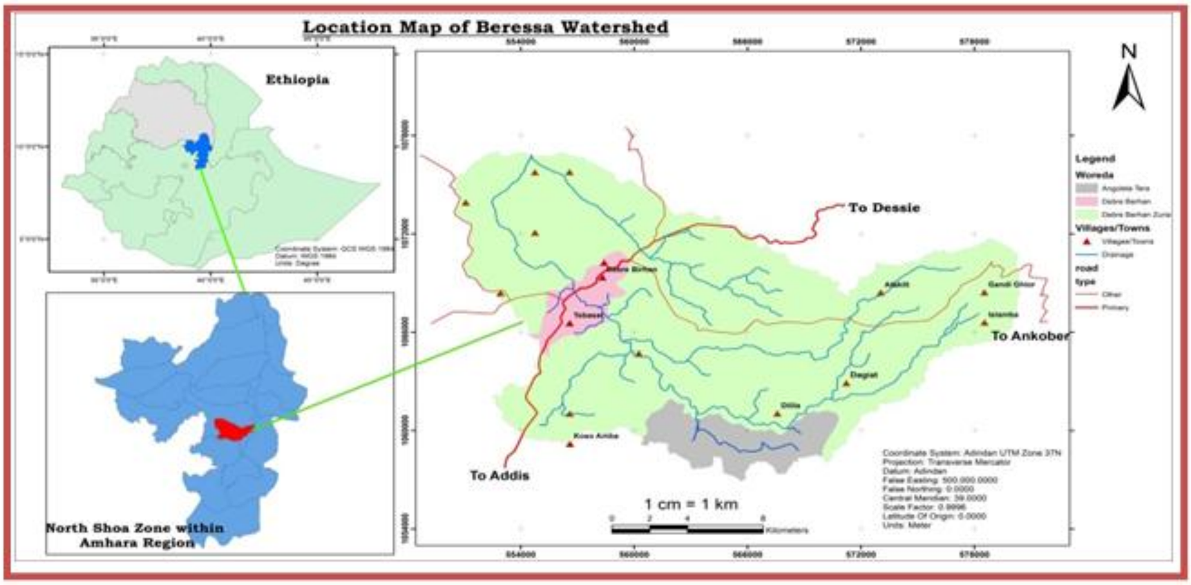


Figure1:LocationmapofBeressa watershed

The geology and hydrogeology of the area is characterized based on data obtained from theGeological Survey of Ethiopia (GSE). Daniel Meshesha, et al., 2010, has studied the geologyof Debre Birhan area and produced the geological map of the Debre Birhan map sheet at ascale of 1: 250,000 based on field observations, petrographic studies, Landsat image analysisand literature studies. Whereas, Hydrogeological and Hydrochemical Maps of Debre Birhanmap sheet was made by collaboration of Czech Geological Survey and Geological Survey ofEthiopia,2018.

To estimate the groundwater recharge based on WB method, daily precipitation data for tenyears(2004-2013) is utilizedfromCFSR(Climate ForecastSystemReanalysis)dataset.Monthly average Potential Evapotranspiration (PET) and Actual Evapotranspiration (AET) iscalculatedusing Thorenthwaitemethod.The averageannualrunoffforthewatershed iscalculated using Curve Number (CN) method. This is made by calculating the runoff amountfor each rainfall day as a function of the CN. The daily runoff values were summed up to getthe total annual runoff. The annual groundwater recharge of the watershed is then calculatedastheresidual ofthetwowaterbalance componentsfrom theannualprecipitation.

The SWAT model takes two types of input data for analysis purpose: projected maps (LULC,Slope and Soil) and daily weather data (Temperature, Precipitation, Wind Speed, RelativeHumidity and Sunshine Hours). The three maps were reclassified in to different class to makethemcompatiblewith SWAT database.Different software was also used as a tool to characterize the watershed and estimate theannualgroundwaterrecharge.ArcGISanditsSWATextensionwereusedtodelineatewatershed, extract drainages and run the SWAT model. Arc Map 10.1 is used to preparedifferentmaplayersforthewatershed.Surfer15isalsousedtocharacterizethephysiography and produce 3D map of the watershed. Microsoft Excel, on the other hand, isusedtomakedifferentcalculationofWBcomponents, includingthe groundwaterrecharge.

2. WATERSHEDCHARACTERISTICS

2.1 SizeandShape

The size of a watershed is best explained in terms of its area (A) and Perimeter (P), whereasGravelius coefficient or compactness index (K) can be used to express its shape. The area ofBeressa watershed is 340.594 km^2 and its perimeter is 141 km calculated using Arc map.Gravelius coefficient or compactness index (K), devised by Gravelius, expresses the ratio oftheperimeterofthedrainage-basin to that ofacircle ofequal area, or

$$k = \frac{P}{P^*} = \frac{P}{2\sqrt{\pi A}}$$

Where,Pisperimeterofthebasin,P*isperimeterofacirclehavingthesamearealextentA.Theminimumvalueis unityfor acirculararea(Horton,1932)

$$k=\frac{141km}{2\sqrt{3.14*340.594km2}}=\mathbf{2.155787}$$

Thecompactnessindexshowsthatthewatershedisnotcircularinshape,itisratherelongated.Thevisualshapeofthewatershedcanbeseen fromthelocationmapgivenabove.

2.2 PhysiographyandSlope

The local physiography of the area has been characterized based on SRTM 30m DEM data.Thetopographyshowsthreedistinctclasses:ruggedmountainousregionintheEasternpartof the watershed(along the recharge areas), extensive plateauregion in the central andsouthern part of the watershed and localized, deep and rugged gorges in the north westernregionalongtheoutletofthewatershed.Theelevationofthewatershedrangesfrom2099mto3646m a.s.lfrom thedeepgorgesto themountainousterrains,respectively.

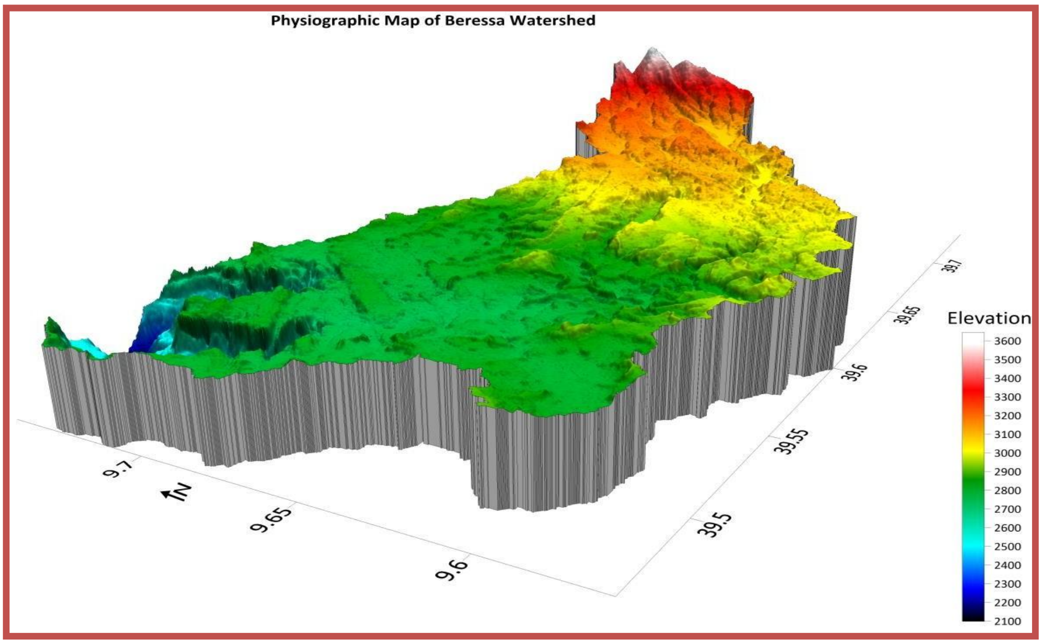


Figure2:Physiographic mapofBeressawatershed

Slope gradient of the study watershed is classified into five classes: 0-5, 5-11, 11-19, 19-31,31-74 degrees, which represent from near horizontal to very steep slope areas. The highestslopes are found in the river gorges and mountains, where as the central plateau areas arerelativelynearhorizontal.

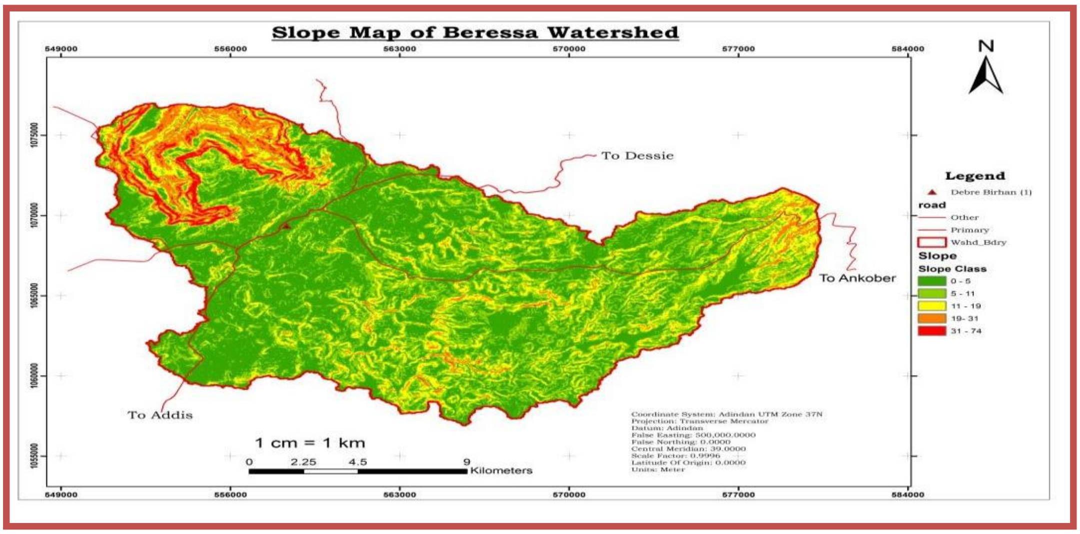


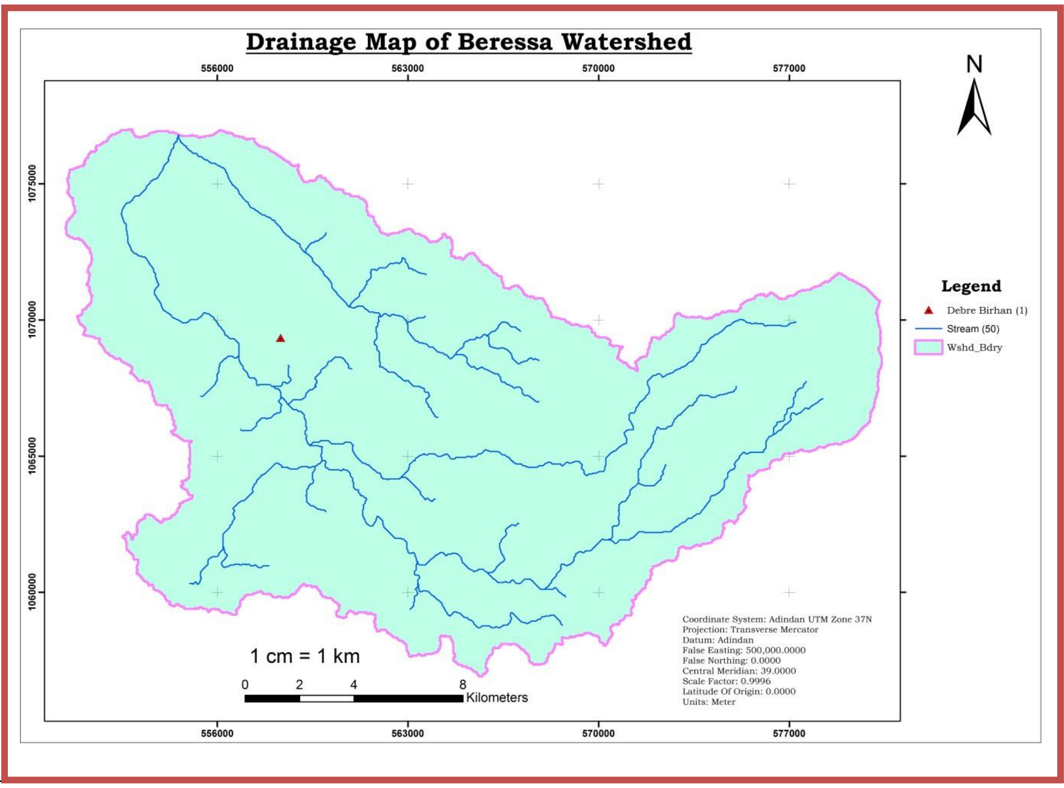
Figure3:Slope mapofBeressa watershed

2.3 DrainageDensityandDrainagePattern

Streams and rivers in the Beressa watershed start from the eastern part of the area and drainfirst to south west and then to northwest towardsthe watershed outlet. The two major riversin the watershed are Beressa and Dalecha rivers. Beressa River is perennial, whereas DalechaRiver is intermittent and the two rivers bound Debre Birhan city from South-West and North-East direction, respectively. The drainage pattern of the river networks is not the same atdifferent sectors of the watershed. It has semi-parallel drainage pattern on the eastern andsouth western side (downstream and upstream areas), while dendritic drainage pattern isobservedin thecentral part.

Figure4:DrainagemapofBeressa watershed

Drainage-densitydefines thelengthofstreams perunit ofdrainage-area,or mathematically:



d d = A

$\underline{L}_T$

= d

d

324Km

340.594Km2

Where, d_d – drainagedensity

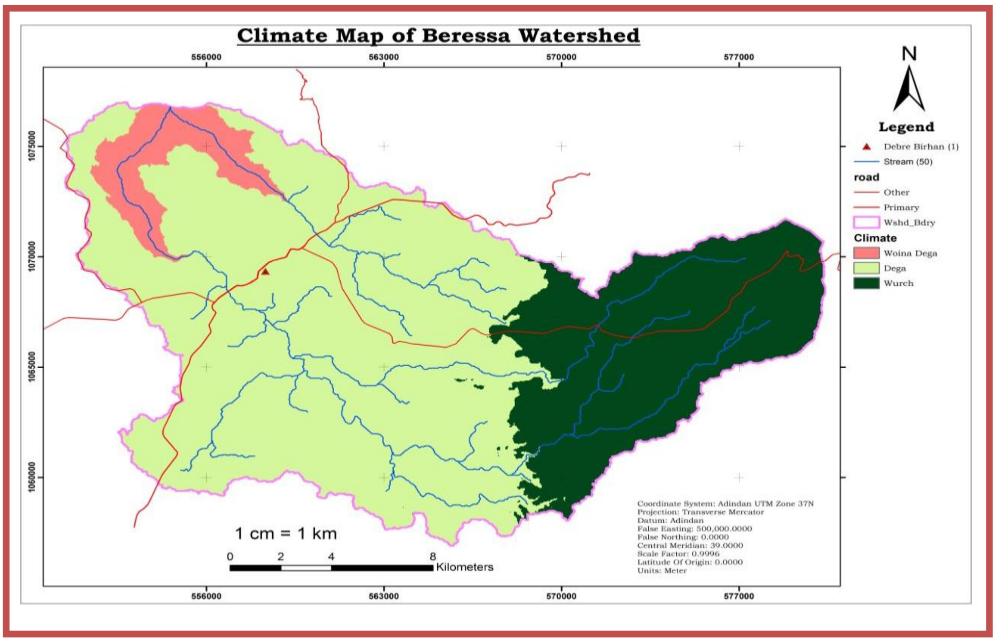
L_T- the whole length of stream networks, andA-total areaofthewatershed.
=**0.9513 perKm**

Drainage-density is an excellent indicator of the permeability of the surface of a drainage-basin,itsvaluerangingfrom1.5to2.0forsteep,imperviousareasinregionsofhighprecipitation, down to zero or nearly zero for basins sufficiently permeable so that all therainfallordinarilyistakenintothesoilthroughinfiltration(Horton,1932).Hence,thewatershedhas moderatedrainagedensity.

2.4 Climate

The climate of Ethiopia is mainly controlled by the seasonal migration of the Inter-tropicalConvergence Zone (ITCZ) following the position of the sun relative to the earth and theassociated atmospheric circulation. It is also highly influenced by the complex topography ofthecountry.Therearefivetraditionalclimateclassesinthecountry:Wurch(representingvery cold climate at elevations greater than 3000m a.s.l), Dega (representing temperate likeclimate in the highlands with altitude range of 2500-3000m asl), WoinaDega (warm climaterepresenting areas with altitude ranges of 1500-2500m a.s.l), Kola (hot and arid type climatein an areas with elevation less than 1500m a.s.l.) and Bereha (typical of areas with very hotand hyper-arid climate)(NMSA, 2001). According to this classification, Beressa watershedlies within three different climate regions: Wurch, Dega and WoinaDega. Most part of thearea lies within Dega climate region, where as Wurch and WoinaDega climate types areconstrainedto theUpstreamand Downstreamareasofthewatershed, respectively.

Figure5:Climate mapofBeressawatershed



CFSR is used as a source of data for climatic elements (Precipitation, Temperature, Windspeed, Sunshine Hours and Relative Humidity. The CFSR dataset consists of hourly weatherforecasts generated by the National Weather Service‟s NCEP Global Forecast System. It is aglobalmeteorologicaldatasettoobtainhistoricalweatherdataavailablegloballyforeachhour since 1979 at a 38-km resolution. According to Fuka et al., (2013) utilizing the CFSRprecipitation and temperature data to force a watershed model provides stream dischargesimulations that are as good as or better than models forced using traditional weather gaugingstations, especially when stations are more than 10 km from the watershed. Based on thisstudy conducted on five watersheds in USA and Ethiopia, the authors have made someconclusions. CFSR data is globally available and will allow modelers access to weather datawhere there are no nearby weather stations. This is probably most valuable for data-poorregionssuch asin developing countries.The weather dataare effectively averagedoverspatial scales that are similar to many watershed extents or at least more similar than a typicalpoint measurement of a weather station is to a watershed. CFSR data typically offers dailydata continuously for the years (1979-2014). However, data from weather stations are usuallydiscontinuousand extrapolatingthedatacould bemisleading.

The weather data of the watershed averaged for 10 years from 01/01/2004-31/12/2013 ispresentedin ChapterFour.

2.5 LandUseLandCover(LULC)

The LULC of an area is one of the most important determinant factors for the water resourcepotential of an area. In groundwater recharge, it controls areas of rainfall percolation andrunoff generating areas. The LULC data of the area was found from 20m resolution Sentinel-2LULC mapofEthiopia.

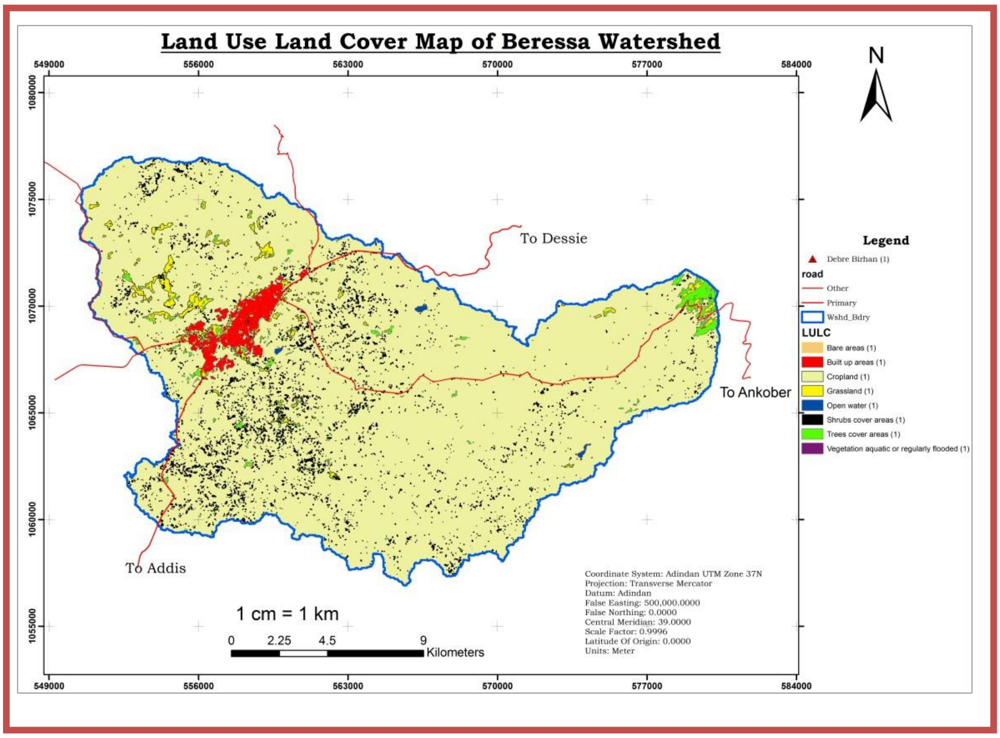
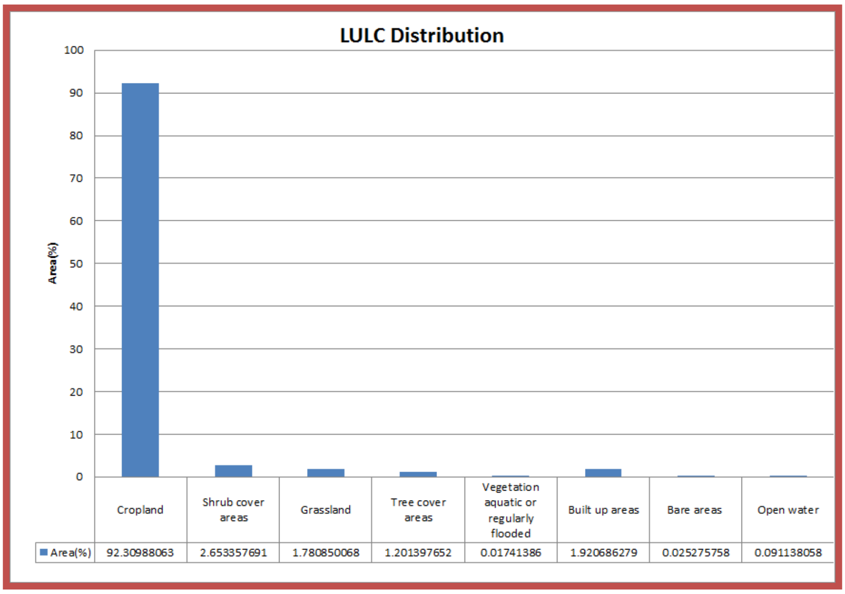


Figure6:LULCmapofBeressa watershed

Based on the LULC map, the watershed is divided into eight land cover classes: Cropland,Shrubcover areas,Grassland,Tree coverareas,Aquaticor regularly floodedVegetation,Built up areas,Bare areasandOpenwater. Themain cropsgrownin the regionincludebarley,wheat,beans,fieldpeas,andlentils.Farmingisalmostentirely rain-fed,andisdependent on weather conditions. The chart below shows the percentage distribution of eachlandcoverclass in thewatershed.

Figure7:Percentagedistributionofeachlandcover class



2.6 Soil

The soil groups of Beressa watershed are classified according to the FAO soil group. As aresult, three soil classes are distinctly mapped: VerticCambisols (CMv), EutricLeptosols(LPe)andLithicLeptosols(LPq).Cambisolsholdssoilswithincipientsoilformation.Cambisol soils show beginning transformation of soil material from weak, mostly brownishdiscolorationand/orstructureformationbelowthesurfacehorizon.VerticCambisolsoilshave fine top soil texture, 30%, 28% and 42 % Sand, Silt and Clay proportion, respectivelyand are classified as light clays based on USDA texture classification. EutricLeptosols havemedium topsoil texture, 50%, 20% and 30% proportion of Sand, Silt and Clay respectivelyand are classified as loam soil. Lithic Leptosols have medium topsoil texture, 43%, 29% and28% proportion of Sand, Silt and Clay respectively andare classifiedas clay loam soils(FAO,2009).
Basedondatafrom(BeleteBerhanuetal.,2013)thehydrologicgroupofthesoilsisclassifiedasBand D.

Textureclass	**Effective watercapacity(Cw)(mm)**	**Infiltration rate (f)(mm/hour)**	**Hydrologic**
Sand	8.89	210.1	A
Loamy sand	7.874	61.2	A
Sandyloam	6.35	25.9	A
Loam	4.826	13.2	B
Silt loam	4.318	6.9	B
Sandyclay loam	3.556	4.3	C
Clayloam	3.556	2.3	D
Siltyclayloam	2.794	1.5	D
Sandyclay	2.286	1.3	D
Siltyclay	2.286	1.0	D
Clay	2.032	0.5	D

Table 1: Soil Infiltration rate and hydrological soil group based on textural class (adopted from BeleteBerhanuetal.,2013)

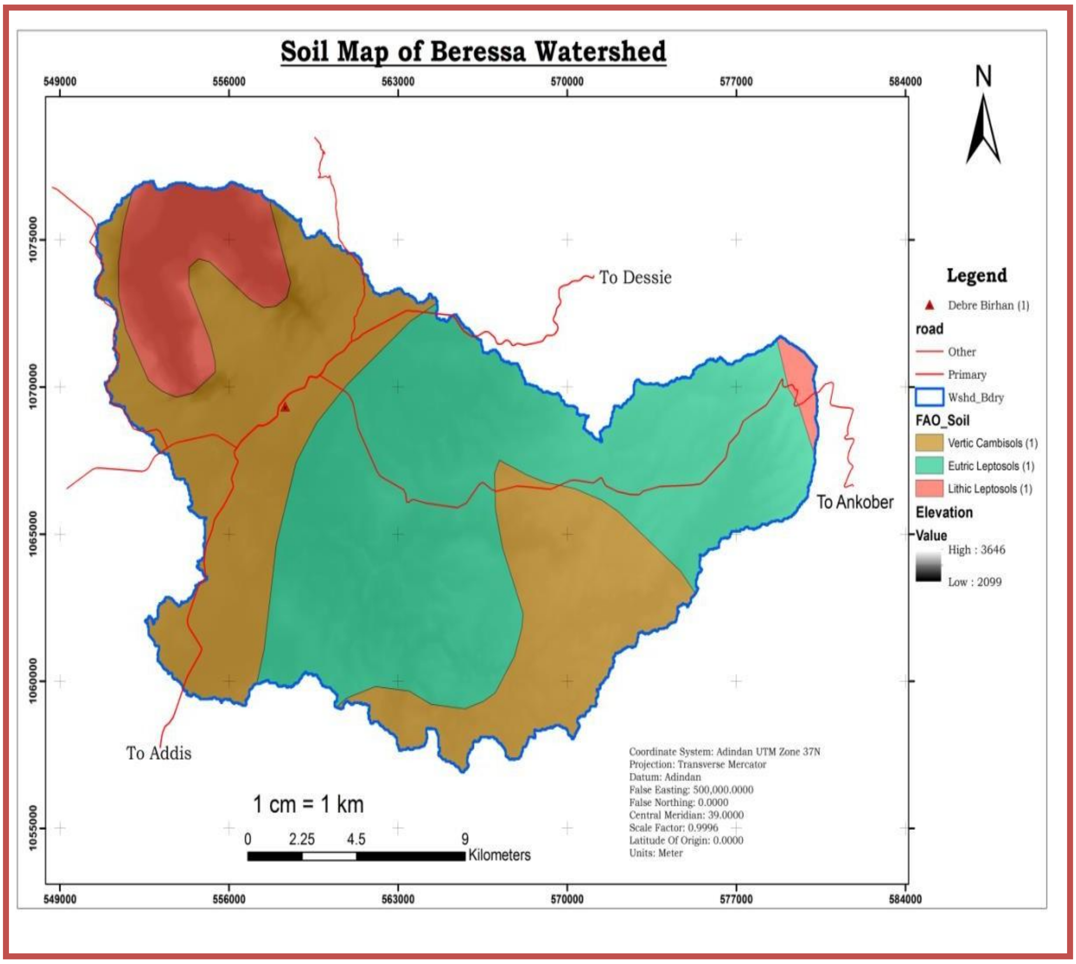


Figure8:Soilmap ofBeressa Watershed

3. GEOLOGY AND HYDROGEOLOGY OF BERESSAWATERSHED

3.1 GeologyofBeressaWatershed

Beressa watershed is located within the central Ethiopian Plateau along the North-Westernmargin of Main Ethiopia Rift System. According to Daniel Meshesha et al (2010), the studyareaconsistsoftwolitho-stratigraphicunits,CenozoicvolcanicrocksandQuaternarysuperficial deposits. Cenezoic volcanic rocks which are found in the study area are formedduring the tertiary volcanism and these rocks include Tarmaber-Megezez basalt and SelaDengay-DebreBirhan-Gorgo ignimbrite. On the other hand, a Quaternary superficial depositcommonin thewatershed is Eluvium deposit.

3.1.1 Lithostratigraphicunits

The main governing factor for the hydraulic characteristics of ground water is the rock unitswhich found in the area. To characterize the hydraulic properties of the rocks in the area wehave usedlocalandregionalpreviously workeddata. Accordingly the area iscovered bythree different lithologic units which have different age and history. These rock units arepresented as follow in age wise from oldest (SelaDengay-DebreBirhan-Gorgo ignimbrite) toyoungest(Eluvium)superficial deposits.

SelaDengay-DebreBirhan-GorgoIgnimbrite

According to Daniel Meshesha et al (2010) this unit has sharp contacts with the overlying(TarmaberMegezez,)andunderlying(Kesem)basalts.Itcomprisesignimbrite,rhyolite,Tertiary sediment, tuffaceous sediment, aphanitic basalt, agglomerate and ash. The ignimbriteforms gentle to steep cliffs, elongated ridges and sporadically distributed isolated hills. It ismedium to coarse grained, light/bluish/brownish gray to gray (fresh color) to dull/dark gray(weathering color), highly consolidated to welded tuff and bedded. It also shows columnarjoint,verticaljoints,andfractures.Itcontainsrockfragmentsofrhyoliteandbasaltrangingup to 2cm in diameter and elongated fibrous glass shards (fiamme), whereas the amount ofrock fragments significantly varies from place to place. The thin section studies show theignimbrite has an average composition of glass 60%, plagioclase 25%, rock fragments 8%,quartz 5%, sphene 1% and iron oxide 1%. Rhyolite is also found in SelaDengay-DebreBirhan-GorgoIgnimbrite.Itisfinetomediumgrained,bluish/light/greenishgray (freshcolor)todullgray,light/darkbrown(weatheringcolor).Itishighlyfracturedandvertically jointed. The thin section studies show the rhyolite has An Average composition of glass 50%,plagioclase 30%, quartz 15% and pyroxene 1%. Plagioclase is altered to sericite. The rockexhibits cryptocrystallinetexture.

Tarmaber-MegezezBasalt

According to Daniel Meshesha et al (2010) it has sharp contact with the underlying SelaDingay-DebreBirhan-Gorgo ignimbrite. Termaber-Megezez basalt includes fine, medium tocoarse-grained, dark gray (fresh color) to light/reddish/dark/yellowish brown (weatheringcolor) and aphanitic to porphyritic basalts. It is characterized by different phases of basalticflows separated by randomly exposed reddish palaeosols and reddish brown scoriaceousbasalts(0.5-8mtthick).Itisdominantlyrepresentedbyplagioclasephyricvarieties(plagioclase phyric and olivine-plagioclase phyric basalts) together with minor olivine phyric,pyroxene phyric, plagioclase-pyroxene-olivine phyric and aphanitic basalts. It is medium tocoarsegrainedanddarkgray,containingplagioclasephenocyrstsupto5cminlength.Petrographicstudiesoftheplagioclasephyricbasaltshowanaveragecompositionofgroundmass35%,plagioclase30%,pyroxene(augite)10%,olivine12%andopaqueminerals10%.Plagioclaseandolivinegrainsarealteredtosericiteandiddingsite.Thegroundmassisdominatedwithplagioclaseandpyroxenemicrolaths.Therockexhibitstrachytic, porphritic, ophitic to seriated textures. Olivine-plagioclase phyric basalt is mediumtocoarsegrained,darkgray(freshcolor)todullgray(weatheringcolor),phyricwithdominant plagioclase and few olivine phenocrysts. Petrographic studies of olivine-plagioclasephyric basalt show an average composition of groundmass 45%, plagioclase 30%, pyroxene3%, olivine 8% and opaque minerals 10%. Plagioclase and olivine are altered to sericite andiddingsite(mostlyalongfractures)respectively.Thegroundmassiscomposedofmicrocrystals of olivine, plagioclase,and opaque minerals. The rock exhibits porphyritic toseriated textures. Olivine phyric basalt forms a ridge with blocky appearance. The rock iscoarsegrained,greenishgray(freshcolor)togray(weatheringcolor).Ingeneral,thedominant Tarmaber-Megezez basalt (plagioclase phyric basalt) gradually ranges to aphaniticbasalt with no or few phenocrysts. The aphanitic basalt is fine grained, black and dark/lightgray (fresh color) to gray and dull gray (weathering color), columnar there are scoria depositsassociated with the aphanitic basalt. Petrographic studies show the aphanitic basalt has anaveragecompositionofgroundmass92%,plagioclase 3%,opaque2%andolivine up to1%.

EluviumDeposits

According to Daniel Meshesha et al (2010) the eluvium soil is mostly found on the plateauand escarpment of the map sheet, occupying flat lying and gentle topography cover small partof the study area. It is formed by the gradual weathering of the basalt, ignimbrite and rhyolite.There are rock fragments of basalt, ignimbrite and rhyolite within the eluvium soil. It is silt toclay sized, light/dark gray to reddish brown fertile soil. It is highly ploughed by the localpeople.

3.1.2 GeologicalStructures

As presented above thearea is dominated by volcanic rock types so the hydraulic propertiesof the rocks are controlled by primary and secondary geological structures. Since the studyarea is found along the western margin of main Ethiopian rift valley secondary geologicalstructures are common.Among the common secondary geological structures in the areaincludes faults, joints and shear zones we may act as a conduit for water movement in thesubsurfaceand theywillincreasethepermeabilityofassociatedrock units.

NormalFaults

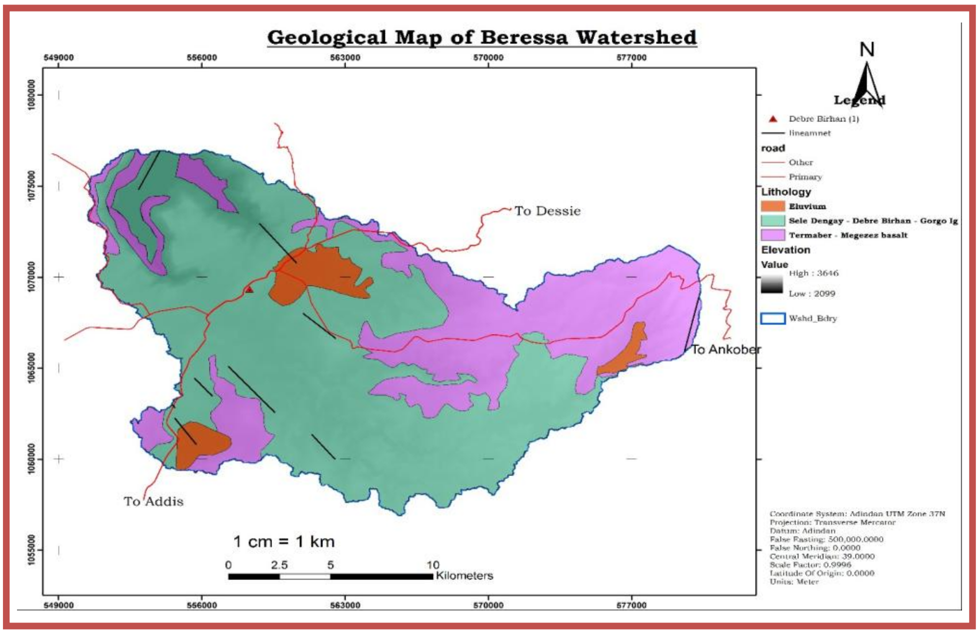
Inthestudyareatwosetsofnormalfaultsareobservedasshowninthegeologicalmap.These Normal faults are NE-SW (including boundary faults and several rift oriented stepfaults)andNW-SEtrendingtranscurrentfaults.Intherift-margintheNE-SWtrendingnormal faults are characterized by a series of parallel step faults having different magnitudes.The NE-SW trending faults have similar orientation with the major main Ethiopian rift borderfault, while the NW-SE tending faults are nearly perpendicular with the major regional borderfaults. Along with the major lithological rock units in the study area these faults will have aneffect on the storage and on the ground water dynamics and this will affect the quality ofaquifer.

JointsandIrregularFractures

Fractures are discontinuities of rock units formed after the formation of the rock units due tobrittle deformation.

The orientation and the degree fracturing control ground water dynamics.Differently oriented joint sets and irregular fracture (few mm to cm in width) are observed inthe Beressa watershed. They are penetrative to non-penetrative joints, having significantlyvariable strike length. Mostly in the ignimbrite two sets of joints are encountered, these arehorizontal(dipping30^0towardsSE)andvertical(trendingNSandN10^0E)setofjoints.In addition irregularly oriented columnar joint sets (mostly hexagonal faces)are also observedin the ignimbrites and basalts (Jiri Sima, 2018). All these irregular fractures and joints willincreasetheporosityandthepermeabilityofrockunits in theBeressawatershed.

Figure9:Geologicalmap ofBeressawatershed(adoptedfromDanielMesheshaetal.,2013)



3.2 Hydrogeologyofthearea

From the hydrogeological point of view, a good aquifer must be sufficiently permeable andtransmissivewithinterconnectedporesandfissuresandwithenoughstoragetoyieldgroundwater. The groundwater bearing potential is also related to faults, and weathered andfractured zones in the rock mass. According to the (Jiri Sima, 2018), geological units are amajor factor that control the quantity and quality of groundwater occurrence in the area.Sedimentary rocks havegreatpotential for groundwater due to their highprimary porosityandpermeabilityrelativetootherrocks.Reclassifyinglithostratigraphicunitsintohydrostratigraphicunitsrequiresinformationonthehydraulicharacteristicsofrocks.Compared to sedimentary rock units, secondary porosity is more important than primaryporosityinigneousandmetamorphicrockunits.Largespatialvariationinrockpermeabilityisacommonfeatureoffracturedvolcanicterrainduetodifferencesinthedegreeoffracturing. In addition to the lithologic units since the study area is dominated by volcanicigneousrocks,secondaryporosityhasa greateffect on thepermeabilityandgeneral hydraulic characteristics of these rock units in the area. Based on the above lithological units and theexistingfracturesdifferenthydraulicpropertiesareexpectedwithinthestudy area.Thehydraulicpropertiesofthese different rockunits in thestudyarea arepresented as follow.

HydraulicCharacteristicsofTarmaber-MegezezBasalt

These basalts have an average yield of wells of 10 l/s and springs of 6 l/s, and are aquiferswith very good secondary porosity and permeability (Jiri Sima, 2018). These basalts aretectonicallyaffectedbytheNNE-SSWtrendingnormalfaults,whichfollowtheriftpropagation. These structures enhance the recharge conditions of the area and, in addition tothe intensive development of fractures, weathered rock and joints in this unit create favorablecondition for their good permeability. The unit has a scoraceous lava flow nature, which ishighly favorable for groundwater storage and movement. The aquifer is recharged directly byrainfall and by infiltration from porous aquifers developed in Quaternary sediments andcovering theplateauarea. The aquifers are also rechargedby perennial riversand theirtributaries.Manyspringsemergingfromthisunitarecontrolledbyfracturesorfaultsintersecting topographical depressions. There are numerous drilled and dug wells from thisaquiferwithgoodyieldsforcommunitywatersupply.

HydrauliccharacteristicsofSelaDengay-DebreBirhan-GorgoIgnimbrite

SelaDengaye-DebreBirhan-Gorgo-Ignimbrite/Trachyte/Rhyolite/Tertiary sediments aquifersof the plateau with an average discharge of well =10 l/s and spring = 1.3 l/s and the boreholessunk in the fractured ignimbrite have transmissivity of between 0.05 and 226 m^2/day and amean transmissivity of 100.3m^2/day (Jiri Sima, 2018). These volcanic plateaus of the Alajiformation comprise ignimbrite, rhyolite, Tertiary sediment, tuffaceous sediment, aphaniticbasalt,agglomerateandash.Itishighlyconsolidatedtoweldedtuffandbeddedwithcolumnar joints, vertical joints, and fractures. The trachyte is also identified by a dark browncolor, and is vesicular, layered and fractured. The trachyte shows faint columnar jointing.These structures facilitate the groundwater flow. The aquifers are recharged by infiltration ofrainfall and infiltration from porous aquifers developed in Quaternary sediments covering theplateauandnearbyrivers.ThedatafromboreholesdrilledintheDebreBirhanareashowhowsignificantthecontributio nofpermeableTertiarysedimentstotheyieldofwells.Usually, fresh basalt, ignimbrite, rhyolite, and trachyte are considered as low permeablelithological units; however, the presence of the porous sediments in between lava flows formsabodythatcanaccumulatealargevolumeofgroundwaterbydrainageofthesurrounding fissured aquifers and contributes to the yield of wells (JirirSima, 2018). These fissured andmixedaquifersoftheplateau representthemost importanthydrogeological unit ofthearea.

HydraulicCharacteristicsof Eluviumdeposits

The eluvium is mostly found on the plateau and escarpment, occupying flat lying and gentlesloping topography. The gradual weathering of the basalt, ignimbrite and rhyolite forms athick cover of Regolith. There are fragments of basalt, ignimbrite and Rhyolite within theeluvial soil. The regolith is from silt to clay in size, and light/dark gray to reddish brown incolor. Dug Wells are used for the purposes of community water supply (Jiri Sima, 2018).Generally, the eluvium is the most important hydrogeological unit in the area especially forshallowgroundwatersources.

4. GroundWaterRechargeEstimation

4.1 WaterBalanceMethod

Groundwater recharge is the process by which water percolates down the soil and reaches thewater table either by natural or artificial methods to replenish the aquifer with water from thelandsurface(Teklebirhan,A.etal,2012).Theestimationofgroundwaterrechargeisregarded as a highly challenging parameter in hydrogeology. It is one of the most importantcomponents in hydrogeologicalcharacterization of aquifer systemsand the major objectivesin hydro-meteorological studies (Berehanu, B. et al, 2017). Ground water at a basin level canbe estimated/quantified using various methods. Water balance is the balance between theincomingwaterintheformofprecipitationandtheoutflowofwaterintheformofevapotranspiration, groundwater recharge and runoff. In some cases there might be a changeinstorage(Soil moisture, groundwaterorwaterbodies). This method is attractive, because it can be applied almost anywhere precipitation data are available. But, there is a drawback of the water balance method due to short comings inherent to the techniques used. Nonetheless, despite its shortcomings, the water-balance method is a powerful tool to understand the main features of recharge processes, if short time steps are used and the spatial variability of components is taken into account (Berehanu, B. et al, 2017).

4.2.1WaterBalanceComponents

Thebasicconcept ofwaterbalancemethod withinagivenperiodoftimeis:

Inputto thesystem-Outflowfromthesystem= Changein storageofthesystem.

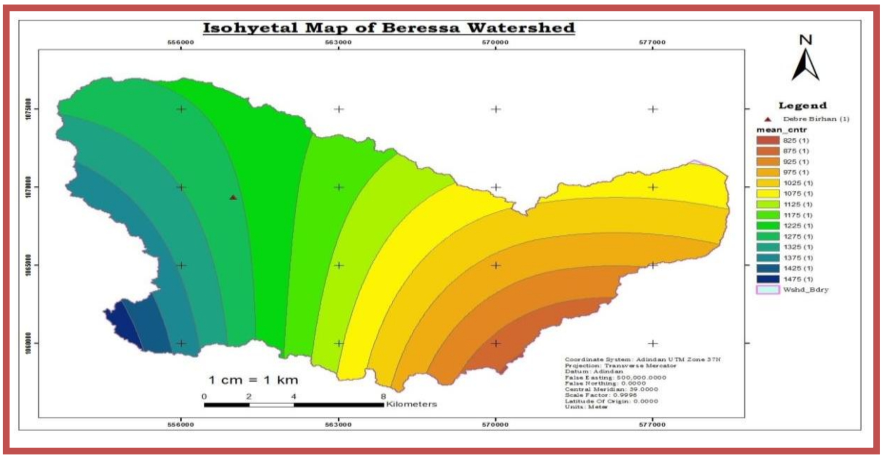
We have used weather data obtained from the NCEP Climate Forecast System Reanalysis(CFSR)dataset,whichisanopenlyavailableglobalreanalysisdatasetthatincludedtemperature and precipitation rate with a spatial resolution on the order of 30 km; and theperiodofrecordincludedadequatehistoricalcoveragetoallowmodelcalibrationandvalidationand extendto thepresent.

Theinflowandout flowcomponentsusedin groundwaterestimation includethefollowing:

a) Precipitation

Precipitation is the main input (inflow) component used in the calculation of ground waterrecharge.Inordertoanalyzetheprecipitationconditionofthearea,tenyearsweighted averagedatafromfourstationsweretakenfromCFSR(ClimateForecastSystemReanalysis). Precipitation map of the area was prepared using Kriging interpolation techniqueinArcGISspatialanalysttoolusingthe4stationsasaninput.Isohytalmapswereconstructed using 4 CFSR stations found in the vicinity of the watershed. The differencebetween two consecutiveIsohytes is used to determine the Isohytal area and the average ofthe two consecutiveIsohyetsis used as the precipitation value for that area. The weightedarea is calculated by dividing the Isohyet area to the total area and this weighted area ismultiplied by the precipitation value. Finally, each weighted precipitation is summed up toestimatethetotalaverageannual precipitation oftheareaand its valueis 1146.83m

Figure10:Isohytal mapofBeressaWatershed



LC	HC	Pi	Ai	At	Ai/At	Ai/At*Pi
800	850	825	147057	340477893.00	0.000432	0.3563286
850	900	875	9500471	340477893.00	0.027903	24.415424
900	950	925	20206125	340477893.00	0.059346	54.895387
950	1000	975	32278952	340477893.00	0.094805	92.434719
1000	1050	1025	42222336	340477893.00	0.124009	127.10926
1050	1100	1075	38320997	340477893.00	0.112551	120.99191
1100	1150	1125	27354762	340477893.00	0.080342	90.385038
1150	1200	1175	29987966	340477893.00	0.088076	103.48942
1200	1250	1225	40248620	340477893.00	0.118212	144.80987
1250	1300	1275	46181360	340477893.00	0.135637	172.93703
1300	1350	1325	30740443	340477893.00	0.090286	119.62917
1350	1400	1375	16428049	340477893.00	0.04825	66.343712
1400	1450	1425	4666087	340477893.00	0.013705	19.528945
1450	1500	1475	2194668	340477893.00	0.006446	9.5076226
Total						**1146.8338**

Table2:AnnualprecipitationestimationusingIsohytalmethod

However, for calculation purpose, data obtained from the SWAT input is used. One objectiveofthisstudy istocomparetheresultsobtainedfromthetwomethods.Hence,similarprecipitation data shouldbe utilized. The average annual precipitation value obtained fromthe SWAT input table is lower, probably because of the method of extrapolation used indetermining the average annual precipitation. The precipitation data obtained from the SWATinputoption is presented in thetablebelow.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Prec(mm)	10.44	34.53	73.56	88.23	54.17	70.8	252.05	255.96	63.65	22.08	12.71	9.26	**947.44**

Table3:Averagemonthlyprecipitationoften yearsdata (2004 -2013)

As we can see from the average monthly precipitation data in the table above, the dry seasonsare observed from October to June whereas the rainy seasons extend from July to September.A small rainy season is observed in otherwise dry season on the months of March and April.Peak rainfall occurs on July and August whereas least rain fall is recorded on November,Decemberand January.

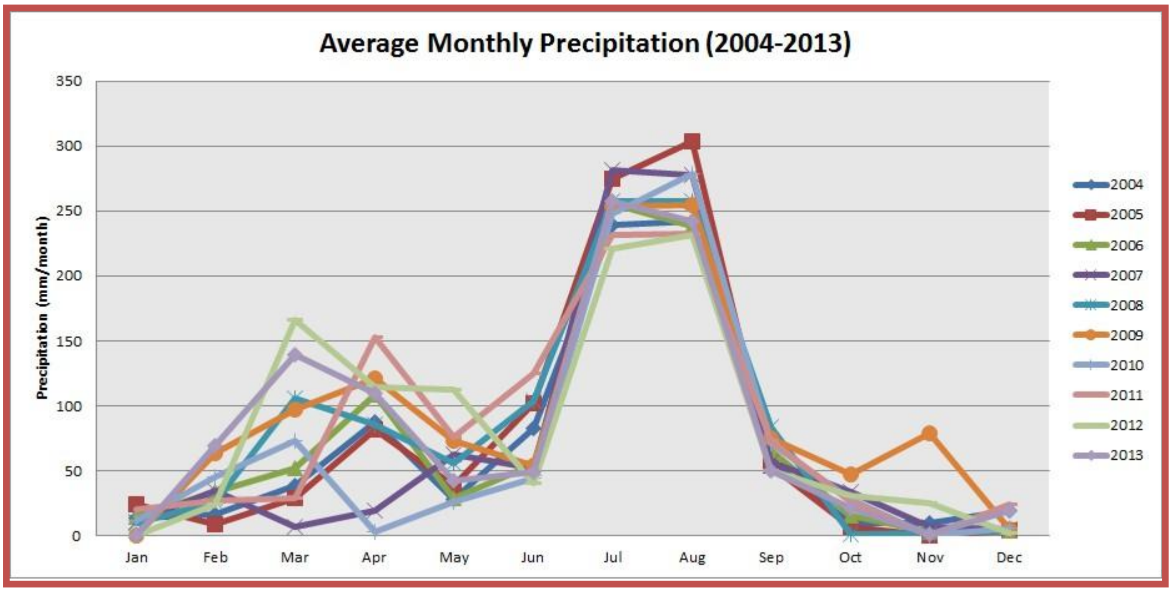


Figure11:Averagemonthlyprecipitation,CFSRdata (2004-2013)

b) Evapotranspiration

One of the output components used in water balance method is the evapotranspiration. Theterm evapotranspiration (ET) is commonly used to describe two processes of water loss fromland surface to atmosphere, evaporation and transpiration. Evaporation is the process whereliquid water is converted to water vapor (vaporization) and removed from sources such as thesoilsurface,wetvegetation,pavement,waterbodies,etc.Transpirationconsistsofthevaporization of liquid water within a plant and subsequent loss of water as vapor through leafstomata(Lincoln,Z. et al., 2010).

i) PotentialEvapotranspiration

Potential evapotranspiration refers to the amount of the possible maximum water loss throughthe process of evaporation and transpiration under unlimited moisture condition. PotentialevapotranspirationiscalculatedusingtheThorenthwaitemethod.Thismethodusesairtemperature as an index of the energy available for evapotranspiration, assuming that airtemperature is co-related with the integrated effect of net radiation and other controls ofevapotranspiration,andthattheavailableenergyissharedinfixedproportionbetweenheating the atmosphere and evapotranspiration. Ten years average air temperature data istaken from Climate Forecast System Reanalysis (CFSR) and potential evapotranspiration iscomputedusingthefollowingformula.

$$Et = 1.6b\left[\frac{10T_a}{I}\right]^a$$

Where,

Et = Potential evapotranspiration in cm/month,Ta=Mean monthlyairtemperature in (^{O}C),
b = latitude correctionI=annualheat index
Usingtenyearmeanmonthlyairtemperature,theannual heatindex is calculated as;

$$I = \sum_{i=1}^{12} \left[\frac{Ta_i}{5} \right]^{1.5}$$

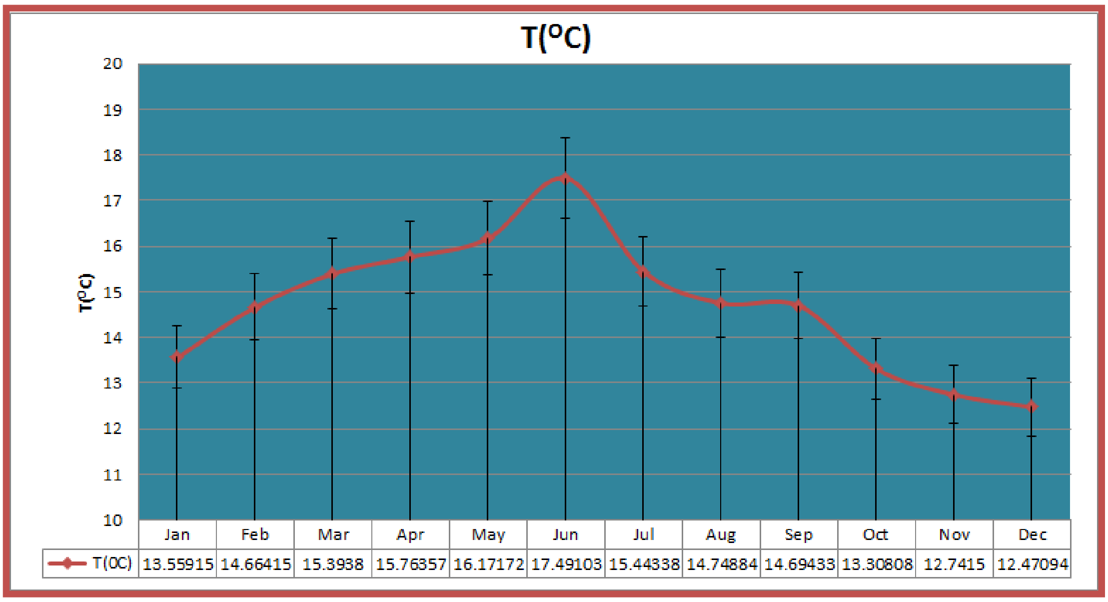


Figure12:AverageMean monthlyairtemperature

The graph above shows that the area is one of the places in Ethiopia with low mean monthlytemperature. The mean monthly temperature of the area attains its lowest value in the monthof December and increases until June, which is the hottest month in the area. The area hasmeanannual temperatureof14.70^{O}C.
By substituting the mean monthly air temperature given in the table into the above equation,thevalueofannual heatindex,Iis foundto be60.74 (i.e.I=60.74).
Then the value of the exponent **a** can be calculated from the annual heat index using thefollowingformula;
$a=0.49+0.0179I-0.0000771I^2+0.000000675I^3$

Thensubstitutingfor I,a=**1.44**

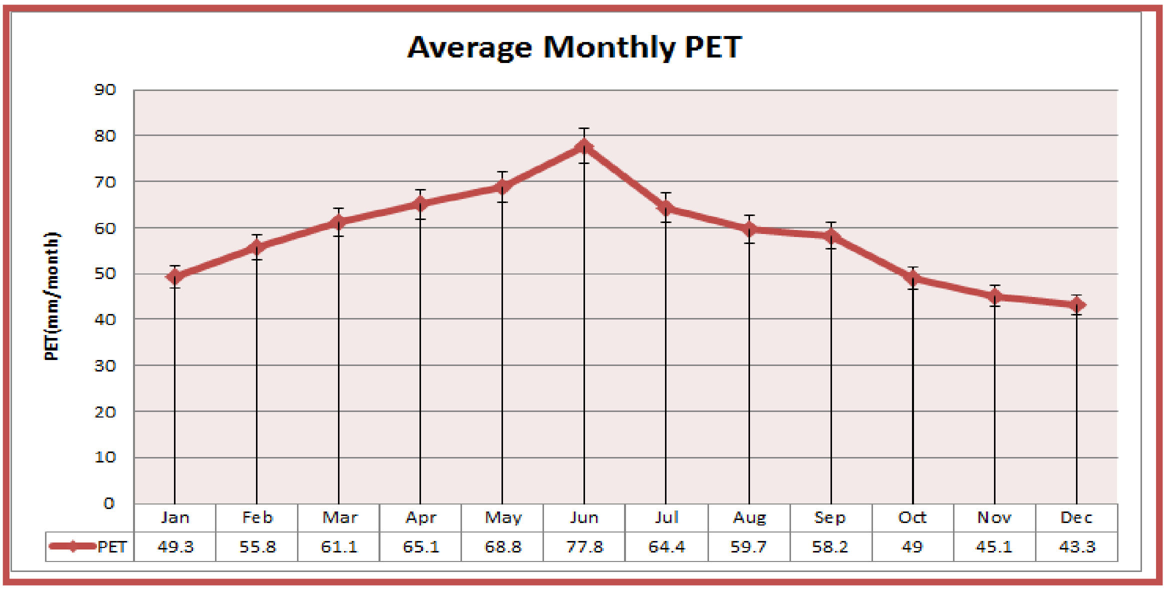
The latitude of the study area is approximated to be 10^{0} N. Hence, the latitude correction (**b**)forthecalculation ofpotential evapotranspirationis givenin thefollowing table.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
b	**0.97**	**0.98**	**1.00**	**1.03**	**1.05**	**1.06**	**1.05**	**1.04**	**1.02**	**0.99**	**0.97**	**0.96**

Table4:Latitudecorrectionvaluesof10^{0}N Latitude

Using the above parameters, potential evapotranspiration is calculated by substituting thesevaluesinto theThorenthwaiteformula. Thevaluesarepresentedinthegraphbelow.

Figure13:Average monthlyPotentialevapotranspiration



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
PET	49.3	55.8	61.1	65.1	68.8	77.8	64.4	59.7	58.2	49	45.1	43.3

As we can see from the above graph, the maximum potential evapotranspiration occurs fromMay to July because in these months the temperature is very high whereas in other months,thepotential evapotranspiration is lowersincethetemperaturelimits thevalueofPET.

ii) ActualEvapotranspiration

Actual evapotranspiration is the amount of water which is evaporated on a normal day whichmeans that if for instance the soil runs out of water, the actual evaporation is the amount ofwater which has been evaporated, and not the amount of water which could have beenevaporated if the soil had had an infinite amount of water to evaporate. Simply, it is theamountwhich actuallyoccursundertheavailablemoisturesituation.

The most difficult parameter to measure when calculating a site's water balance is actualevapotranspiration(AET),whichisafunctionofprecipitation,temperature,solarradiation,soil water storage, wind, canopy and understory interception, and growth rates. The mostpopular method of computing actual evapotranspiration is through the calculation of potentialevapotranspiration. Actual evapotranspiration is calculated from potential evapotranspirationwiththefollowingprocedures(RandallK. Kolkaand AnnT. Wolf,1998):

Step 1: PET- potential evapotranspiration calculated with the Thorenthwaite equation.Step2: P-PET-precipitationlessthepotential evapotranspiration.

Step 3: Accumulated Potential Water Loss (ACPWL) - accumulated potential water loss,whichistheamountofsoilwaterlostwhenPETexceedsP;i.e.,thereislessprecipitationthan potential evapotranspiration. In the calculation of AET, ACPWL is not a factor until P-PETbecomesnegative.TodeterminetheACPWL foraparticularmonth,thepreviousmonth'sACPWLandthecurrentmonth'sP-PETaresummed.Intheoriginalprogram,ACPWLbecomes 0 afteramonth in which PET<P.

Step 4: Soil moisture- soil storage is the maximum soil storage at field capacity (ACPWL =0). When below field capacity (ACPWL < 0), soil moisture is a function of both maximumsoil storageand ACPWL.

Step 5: Delta (change in soil moisture) - the difference between soil storage in successivemonths when it is less than maximum. When DELTA is negative, then AET < PET i.e., soilmoistureis limitingevapotranspiration.Whendeltais positive,thenAET=PET.

$$SM = AWC \exp\left[-\frac{(|ACPWL|)}{AWC}\right]$$

Step 6: Actual Evapotranspiration (AET) - actual evapotranspiration is the sum of availableprecipitation for the month □ the change in soilmoisture. When Delta is positive, AET =PET.WhenDeltaisnegative,AET=precipitationforthemonth+theabsolutevalueofDelta.

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
P	10.44	34.53	73.56	88.23	54.17	70.80	252.05	255.96	63.65	22.08	12.71	9.26
PET	49.30	55.80	61.10	65.10	68.80	77.80	64.40	59.70	58.20	49.00	45.10	43.30
P-PET	-38.86	-21.27	12.46	23.13	-14.63	-7.00	187.65	196.26	5.45	-26.92	-32.39	-34.04
Acc PotWL	-132.21	-153.48	-141.02	-117.89	-132.52	-139.52				-26.92	-59.31	-93.35
AWC	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00
[APWL]	132.21	153.48	141.02	117.89	132.52	139.52	0.00	0.00	0.00	26.92	59.31	93.35
SM Retained	103.26	92.84	98.81	110.93	103.10	99.56	200.00	200.00	200.00	174.81	148.68	125.41
ΔSM	-22.15	-10.42	5.97	12.11	-7.82	-3.55	100.44	0.00	0.00	-25.19	-26.14	-23.27
AET	32.59	44.95	61.10	65.10	61.99	74.35	64.40	59.70	58.20	47.27	38.85	32.53

Table5:StepbystepcalculationofActualEvapotranspiration

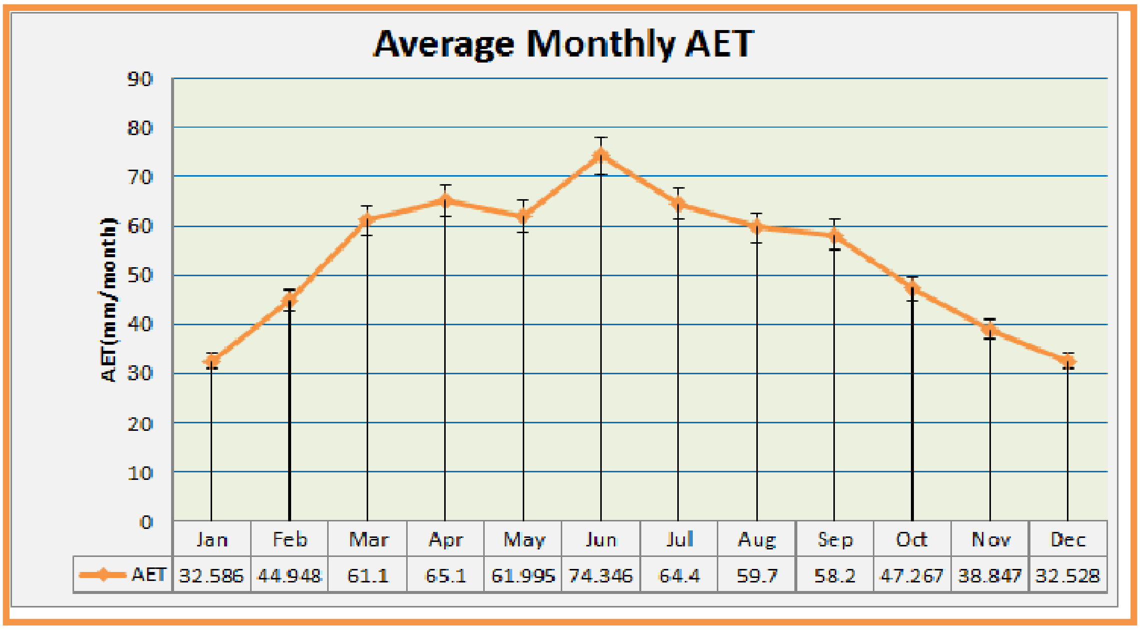


Figure14:Average monthlyactualevapotranspiration

As we can see from the above graph, the highest average monthly actual evapotranspirationunder the available soil moisture condition occurs on June. This is because on this month thetemperature that drives evapotranspiration is higher. On the other hand, the lowest averagemonthlyactualevapotranspirationoccursinDecemberandJanuarysincethereissoilmoisturedeficitin thesemonths.

c) SurfaceRunoff

Runoff is one of the most important hydrologic variables used in most of the water resourcesapplications.Itsoccurrenceandquantityaredependent onthecharacteristics ofrainfall event, i.e. the intensity, duration and distribution. Apart from these rainfall characteristics, there arenumber of catchment specific factors, which have a direct effect on the occurrence andvolume of runoff. This includes soil type, vegetation cover, slope and catchment type (KailasP.,2014).Estimation ofdirect runoffis doneusingthecurvenumbermethod.

The Soil Conservation Service Curve Number (SCS-CN) provides an empirical relationshipfor estimating initial abstraction and runoff as a function of soil type and land-use (Kailas P.,2014). Curve Number (CN) is an index developed by the Natural Resource ConservationService (NRCS), to represent the potential for storm water runoff within a drainage area. TheCN for a drainage basin is estimated using a combination of land use, soil, and Antecedentsoil Moisture Condition (AMC). There are four hydrologic soil groups: A, B, C and D. GroupAhavehigh infiltrationrates andgroupDhavelow infiltration rates.

Surface runoff is calculated using ten year daily precipitation data which is the sum of theweightedprecipitation from fourstationsobtainedfromCFSRusingthefollowingformula:

$$Q = \frac{(P=0.2S)^2}{(P=0.8S)}$$

$$S = \frac{1000}{CN} - 10$$

WhereS-ispotentialmaximum retentionafterrunoffbegins

CN-isknownasCurveNumberassuggestedbytheAmericanSoilConservationService(SCS)

Q- Volume of runoff in inchesP-Rainfall depth ininches

Landuse descriptions	**A**	**B**	**C**	**D**
Commercial,townhouses	80	85	90	95

Cultivatedwithconventionaltillage	72	81	88	91
Forest orwoodsthinstand andpoor cover	45	66	77	83
Pavementandroofs	100	100	100	100
Pasture orrangepoorcondition	68	79	86	89
Farmsteads	59	74	82	86

Table6:Some examplesofCNvalues for differenttypesof soils

The Curve Number (CN) value for the study area is approximated to be 86.63 (i.e. CN =86.63),and usingthis valuepotential maximumretention (S)willbe;
S =(1000/86.63)-10 =**1.54**

Then from the tenyearprecipitation data, tenyear daily precipitation data which is the sumoftheweightedprecipitation(ininches)fromfourstationswhicharegreaterthan0.2*S(Pi>0.2*S or Pi > 0.308) are taken and by substituting these values in the above runoff formula,the daily runoff (Q)values are calculated. The average of these ten year daily values gives thetotal runoff for a given period. When the value of daily precipitation is less than 0.2*S, thevalueofsurfacerunoff(Q)is considered to bezero.
$Q = [\sum(Pi - 0.2\times S)^2/P+0.8\times S]/n =$ **169.655 mm**

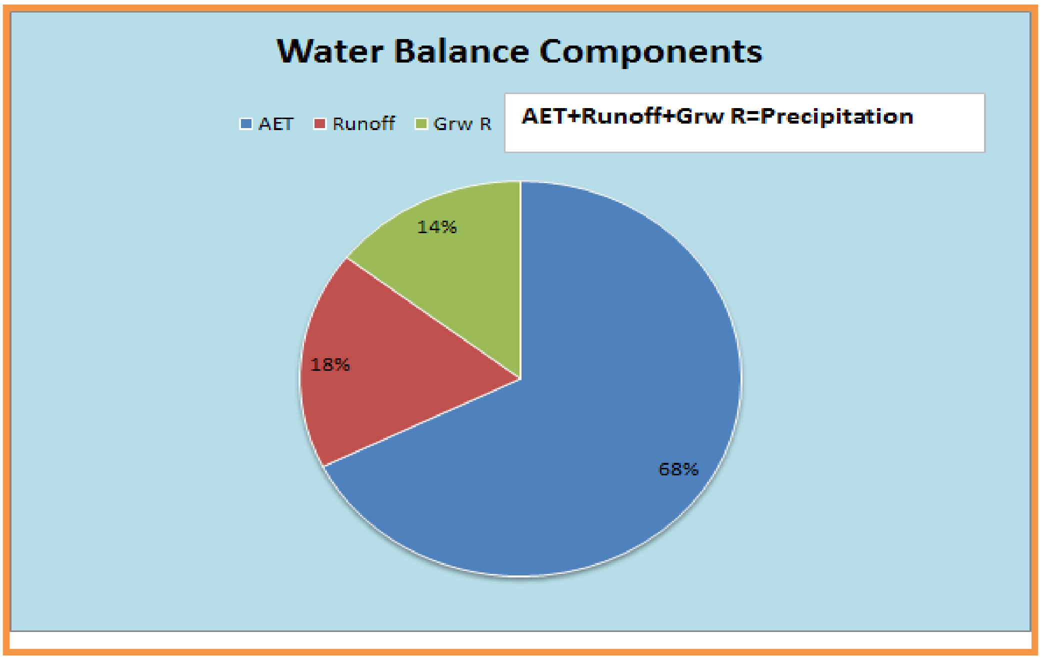
d) Groundwaterrecharge

Therateofreplenishmentofthegroundwater(mainlybyrainfall)isknownasthegroundwater recharge rate. This is the most important parameter required in the successfuldevelopmentofgroundwaterresource,asitisrate(oramountperunittime)whichdetermines the amount of groundwater which can safely be abstracted from wells and bore-holesfromaparticularaquifer(Departmentof Agricultural&Plantation Engineering,2004).
Groundwater recharge is likely to vary in space even over short distances as variations in soiland vegetation parameters can significantly affect the rates of recharge (Cook et al, 1989).Therefore, taking account of spatial variability in estimating recharge is very important ifreasonably accurate replenishment rates to the water table are to be estimated (Department ofAgricultural&PlantationEngineering, 2004).
Groundwater recharge of the study area is calculated using the water balance method asfollows:
Groundwaterrecharge= Precipitation –(Actualevapotranspiration +Surfacerunoff)

By substituting the values of precipitation, Actual evapotranspiration and Surface runoff thevalueofthegroundwaterrechargewillbe:
Groundwaterrecharge(R) =947.44mm– 641.017mm – 169.655mm=**136.768mm**

Generally,aswe canseefromthechartbelowfromthe totalprecipitationof947.44mm,68%(641.017mm)ofitre-evaporatestotheatmosphere,18%(169.655mm)followssurfacepaths

asrunoffand14%(136.768mm)ofitpercolatesthroughthesoillayertoreplenishthegroundwater.
Figure15:ProportionofthefourWater balancecomponents



4.2 GroundwaterRechargeEstimationUsingSWATModel

The SWAT model is a semi-distributed, time-continuous watershed simulator operating on adaily time step (Arnold et al., 2012). SWAT model takes DEM, LULC, soil data, slope,weather data and stream flow data as an input. The last one was not used in this study due tolack of the data and model calibration was not performed. The watershed is divided in to sub-watershed and the sub-watersheds further in to Hydrologic Response Units (HRU). The semi-distributedSWATmodelisbasedonHRUswhichareformedfromoverlappingmapsforsoil, LULC and slope. The principle is that each HRU is composed of specific land use, slopeand soil classes and they have similar hydrologiccharacteristics. (HadilawitTadesse, 2019)In each HRU, two-layer aquifer model, shallow/unconfined aquifer and deep aquifer/confinedaquifer, are used to represent the aquifer system, and a linear reservoir model to simulategroundwater flow. The water of a shallow aquifer could move to the deep aquifer, while thereverseprocess is not allowed (GuangwenShaoet al., 2019)

The size of sub-basin in the watershed will affect the assumption of homogeneity. Hence, thedefinition of a watershed, sub-basin boundaries and streams is decided based on a thresholdarea to define streams (Megersa et al, 2019). A properly projected DEM of 30 m resolutionwas loaded to Arc SWAT interface. Then, the DEM was masked and stream networks werecreated using the loaded DEM. The outlet point was selected from the streams, where the twomainriversBeressaandDalechaRiversmeet.Finally,thesub-watershedsandtheboundaryof the watershed were delineated based on the outlet point defined before. For defining theHRUs, slope, soil and LULC map were loaded using the Land use/soil/slope definition menu.The soil map and LULC map were reclassified using appropriate look up tables, and the slopemap was reclassified in to 5 classes of different slope value ranges. The HRUs were definedby taking multiple HRU within each sub-watershed. In order to increase the number of HRUs(for better accuracy), a threshold of 0% for land use, soil and slope was assigned. Finally, theweatherinputfilewaswrittenusingdailyCFSRweatherdataset.Thewatershedhasanareaof around 341 Km^2 and is divided in to 50 sub-watershed based on each stream within thewatershed, which are further divided in to 800 HRUs. Finally, the model is run over dailybasis from 1/1/2004-31/12/2013 andtheresults wereprinted out onmonthlyscale.

InSWATmodelPETiscalculatedusingPenman-Monteith,whereasRunoffisestimatedwith Curve Number method. The results obtained based on 10 year monthly averaged valuesofthemodel arepresentedbelow.

HydrologicParameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	A
PET	127.7	128.5	158.5	153.0	170.7	158.5	104.6	115.7	145.3	138.7	127.4	119.2	1
AET	7.4	17.4	39.2	50.1	60.9	61.2	81.5	94.3	78.3	42.2	23.9	15.9	5
SurfaceRunoff	0.1	0.9	10.4	21.9	7.6	13.1	69.0	86.4	17.1	0.7	1.3	0.0	2
InterFlow	0.5	0.5	0.9	1.3	1.4	1.3	3.6	5.9	4.8	2.8	1.5	0.9	2
GW percolation	0.0	0.1	1.9	7.0	1.8	5.0	44.7	55.7	10.0	0.2	0.0	0.0	1
Total													9

Table7:AverageHydrologicparametersderivedfromSWATmodel

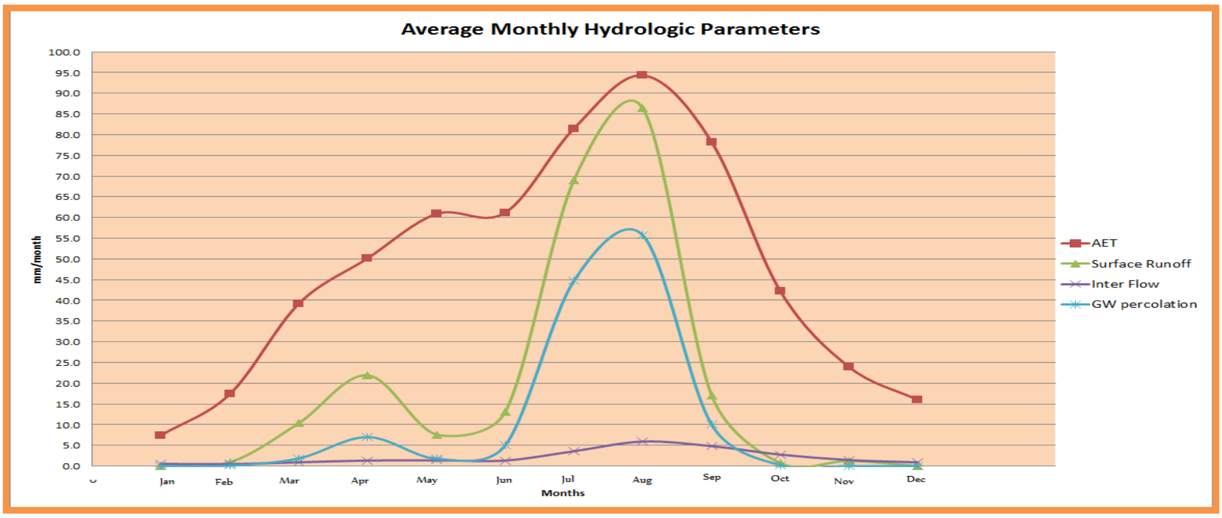
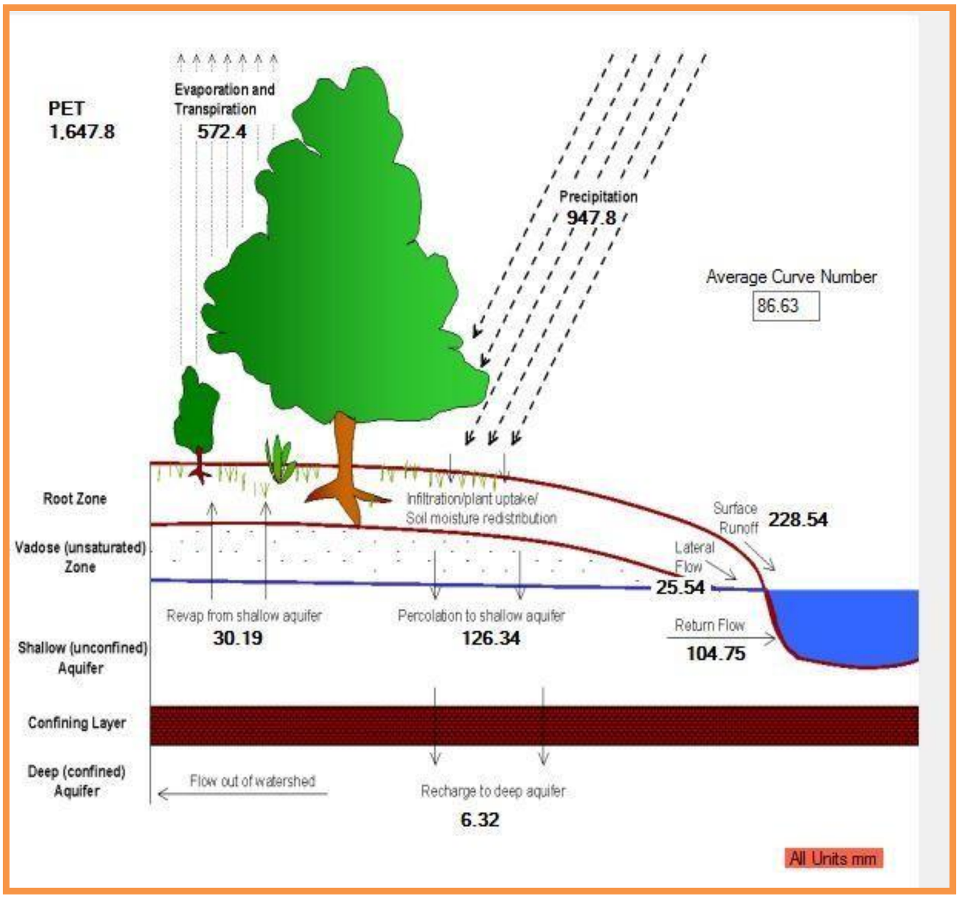


Figure16:GraphshowingaveragemonthlyhydrologicparameterscalculatedusingSWATmodel

The graph above shows continuous monthly increase in AET from January to August and adecrease until December. August is the month with the highest rate of AET, because it is themonth with the highest monthly precipitation and its AET is close to the PET because ofincreasing soil moisture condition. 254.1mm (44.38 %) of the ET occurs in the wet months(July-September).TheGWpercolationandSurfacerunoffshowsimilartrend,wherethethreemonths(July-September)takingthelionsharewith87.34%ofGroundwaterPercolationand75.49%ofRunoffoccurringinthesemonths.Thereis,however,someappreciableamountofGroundwaterpercolationandsurfaceRunoffoccurringbetween

March and April, because of the presence of short rainy (Belg) season. Interflow shows theleast value from the WB components in the watershed. Similarly, it attains its highest valuesin the wet months, but with a slight deviation to the right, possibly because of the larger timeit takes to move through soil particles than surface runoff. The average annual value of theseWBcomponentsisshowninthefigurebelowalongwiththepathsfollowedbyeachcomponent.

Figure17:Averageannualhydrologiccomponentsobtainedfrom SWAT model.



5.DISCUSSIONANDSUMMARY

5.1 ComparisonofWBandSWATModels

The annual groundwater recharge estimation of the watershed has been computed using thetwomethods, and theresultshavebeen explainedabove.

Hydrologic Variables	WB	%fromPrec	SWAT	%fromPrec
Precipitation	947.44		947.44	
PET	697.60		1647.80	
AET	641.02	67.66	572.40	60.42
Surfacerunoff	169.66	17.91	228.50	24.12
Interflow	0.00	0.00	25.50	2.69
GWrecharge	136.77	14.44	126.50	13.35

Table8:ComparisonofWB andSWATmodelforhydrologic variables

Thetwomethodshavepresentedvaluessomesimilarity,especiallytheGroundwaterrecharge, which is the main concern of this study. Considering the cold climate, and clay-loam soils of the area, the lower AET and higher Surface runoff values of SWAT model lookmorereasonable.TheSWATmodelalsopresentsanotheraspectofthewaterbalancecomponent, which is sub-soil interflow flow. The annual Groundwater recharge value of thewatershed estimated using the two methods, however, is very similar and a mean value of**131.63mm/year** is adopted for the watershed. This corresponds to **13.89%** of the annualprecipitation. This is a very reasonable value considering the high Groundwater potential ofthe area under study. It is also agreeable to studies conducted in areas around the watershed.Berehanu, B. et al., (2017) have estimated the annual groundwater recharge of Jema sub-basin to be 133mm, 13.39% of the annual precipitation using WB method. MollaDemlie,(2015) estimated the annual groundwater recharge of Akaki catchment to be 105 mm/a, acatchment with some climatic similarity with Beressa watershed. He referred the above valueas the minimum estimate based on data from other methods and field observation. On theother hand, (TesfayeCherenet, 1988 as cited in Jiri Sima, 2018) classified the different rocksof the area in to aquifer groups of moderate yield. General recharge to groundwater fromrainfallis estimatedto be50 to 150mm/year.

5.2 SustainableYield

There has been a debate on the applicability of the terms safe yield and sustainable yieldamong Hydrogeologists. The term safe yield was first used in 1915 to mean the "quantity ofwater that can be pumped regularly and permanently without dangerous depletion of thestorage reserve" (S. J. Meyland, 2011). A misperception among many hydrogeologists andwaterresourcesmanagersalikeisthatthedevelopmentofgroundwaterisconsideredtobe „safe‟ if the rate of groundwater withdrawal does not exceed the rate of natural recharge.Even with a pumping rate smaller than the natural recharge (so called safe yield), pumpingmay have induced recharge and decreased discharge. The induced recharge may have causedthedepletionofstreamflowandresidualdischargemaynotbesufficienttomaintaingroundwaterdependentecosystems.Furthermore,pumpingalwayscreatesaconeofdepression, which may cause intrusion of bad quality water and land subsidence (YangxiaoZhou,2009)

On the other hand, sustainable yield is the extraction and use of groundwater resources in awaythatdonotcreateunacceptableenvironmental,economic,orsocialconsequences(YangxiaoZhou,2009).Theestimationofsustainableyieldofanarearequiresdetailinvestigation and modeling of the aquifer system and interaction with the ecosystem of thearea. However, (S. J. Meyland, 2011) indicate that a set aside of anywhere from 10 to 40% ofannualGWrechargeseemsreasonable.

Taking the highest value of the above assumption, it is assumed that 40% of the annual GWrecharge(52.65mm)canbeextractedannuallywithoutadverselyaffectingthenaturalecosystem of the area. In volumetric terms, 44.83 MCM is being recharged annually for thetotalwatershed, from which **17.93 MCM**isthesustainableyield.

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