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

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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, SWATModels, 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 itsoccurrenceisthemainfactor, which makesourPlanet,TheEarth,uniqueinthesolarsystem. 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 humankindby 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,about96.54percentofthetotalamountofwaterisintheoceansandisnotdirectlyusable.Similarly, glaciers and ice caps cap 1.74 percent of the total water. This makes Groundwater themost abundant (1.69 %) water resource for direct household 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).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 Southeastern 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.

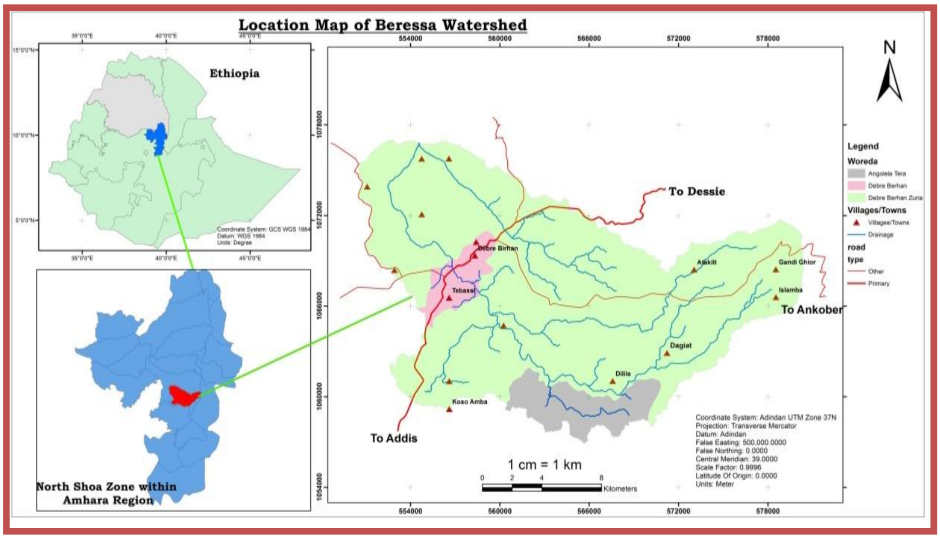

Figure 1: Location map of Beressa watershed

1.3 Objectives

The main objective of this study is to estimate annual groundwater recharge of the watershedusingWBand SWAT mode

Specificobjectivesinclude:

✓ Tocharacterizetheareaintermsofphysiography,drainage,soilcover,LandUseLandCover(LULC),geologyand hydrogeology.

✓ Toestimateaverageannualwaterbalancecomponents,Precipitation,Evapotranspiration,Runoffand GroundwaterrechargeusingWBandSWATmodel

✓ Tocompare groundwaterrechargeestimation usingthetwomethods.

✓ Toestimatetheamountofsustainableyieldinthe watershed

1.4. Methodology and Materials

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 Ethiopiaforthe year 2016. On theotherhand,FAOdigitalsoilmapofEthiopiaisusedtocharacterizethesoiltypeofthewatershed.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 DebreBirhan area and produced the geological map of the DebreBirhan 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 DebreBirhanmap 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 ten years (2004-2013) is utilized from CFSR (Climate Forecast System Reanalysis) dataset. Monthly average Potential Evapotranspiration (PET) and Actual Evapotranspiration (AET) is calculated using Thorenthwaite method. The average annual runoff for the watershed is calculated using Curve Number (CN) method. The annual groundwater recharge of the watershed is then calculated as the residual of the two water balance components from the annual precipitation.

II. Watershed Characteristics

2.1. Size and Shape

The size of a watershed is best explained in terms of its area (A) and Perimeter (P), whereas Gravelius coefficient or compactness index (K) can be used to express its shape. The area of Beressa watershed is 340.594 km2 and its perimeter is 141 km calculated using Arc map. Gravelius coefficient or compactness index (K), devised by Gravelius, and expresses the ratio of the perimeter of the drainage basin to that of a circle of equal area.

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

Thecompactnessindexshowsthatthewatershedisnotcircularinshape,itisratherelongated.Thevisualshapeofthewatershedcanbeseen fromthelocationmapgivenabove

2.2. Physiography and Slope

The local physiography of the area has been characterized based on SRTM 30m DEM data. The topography shows three distinct classes: rugged mountainous region in the Eastern part of the watershed (along the recharge areas), extensive plateau region in the central and southern part of the watershed and localized, deep and rugged gorges in the northwestern region along the outlet of the watershed. The elevation of the water shed ranges from 2099m to 3646m a.s.l from the deep gorges to the mountainous terrains, respectively.

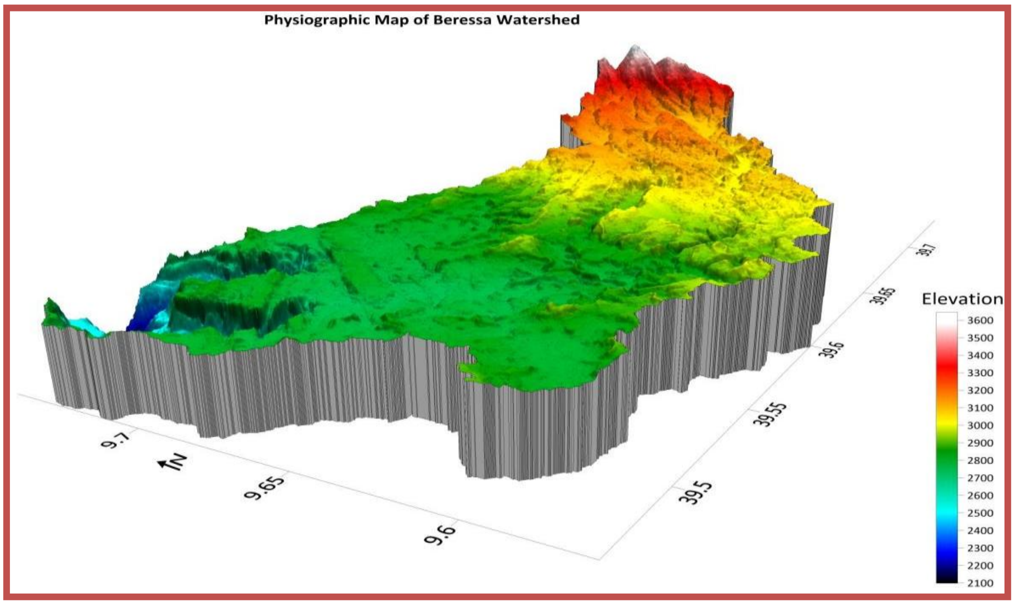

Figure 2: Physiographic map of Beressa watershed

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 highest slopes are found in the river gorges and mountains, where as the central plateau areas are relatively near horizontal.

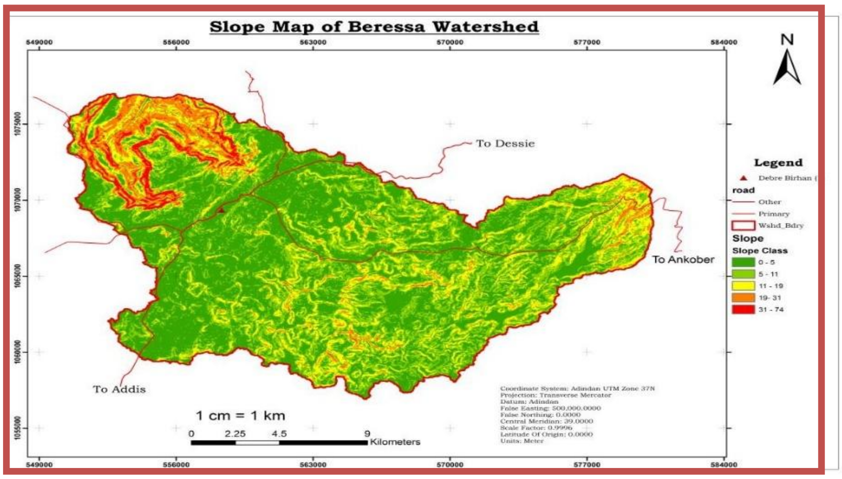

Figure 3: Slope map of Beressa watershed

2.3. Drainage Density and Drainage Pattern

Streams and rivers in the Beressa watershed start from the eastern part of the area and drain first to southwest and then to northwest towards the watershed outlet. The two major rivers in the watershed are Beressa and Dalecha rivers. Beressa River is perennial, whereas Dalecha River is intermittent and the two rivers bound DebreBirhan city from South-West and North- East direction, respectively. The drainage pattern of the river networks is not the same at different sectors of the watershed. It has semi-parallel drainage pattern on the eastern and southwestern side (downstream and upstream areas), while dendritic drainage pattern is observed in the central part.

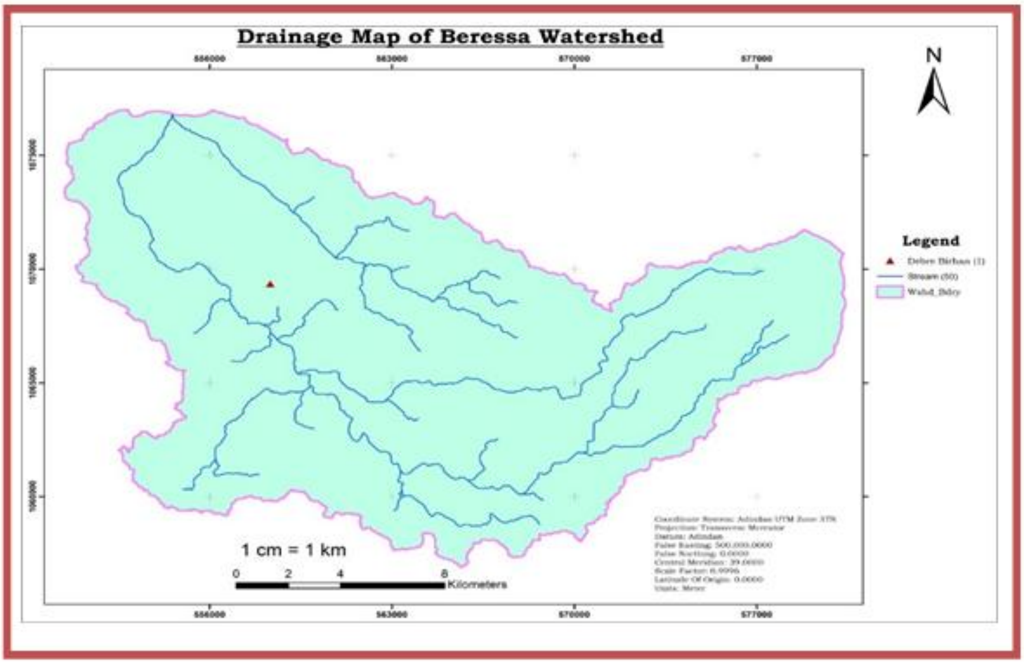

Figure 4: Drainage map of Beressa watershed

2.4. Climate

The climate of Ethiopia is mainly controlled by the seasonal migration of the Inter-tropical Convergence Zone (ITCZ) following the position of the sun relative to the earth and the associated atmospheric circulation. It is also highly influenced by the complex topography of the country. There are five traditional climate classes in the country: Wurch (representing very cold climate at elevations greater than 3000m a.s.l), Dega (representing temperate like climate in the highlands with altitude range of 2500-3000m asl), WoinaDega (warm climate representing areas with altitude ranges of 1500-2500m a.s.l), Kola (hot and arid type climate in an areas with elevation less than 1500m a.s.l.) and Bereha (typical of areas with very hot and hyper-arid climate)(NMSA, 2001). According to this classification, Beressa watershed lies within three different climate regions: Wurch, Dega and WoinaDega. Most part of the area lies within Dega climate region, where as Wurch and WoinaDega climate types are constrained to the Upstream and Downstream areas of the watershed.

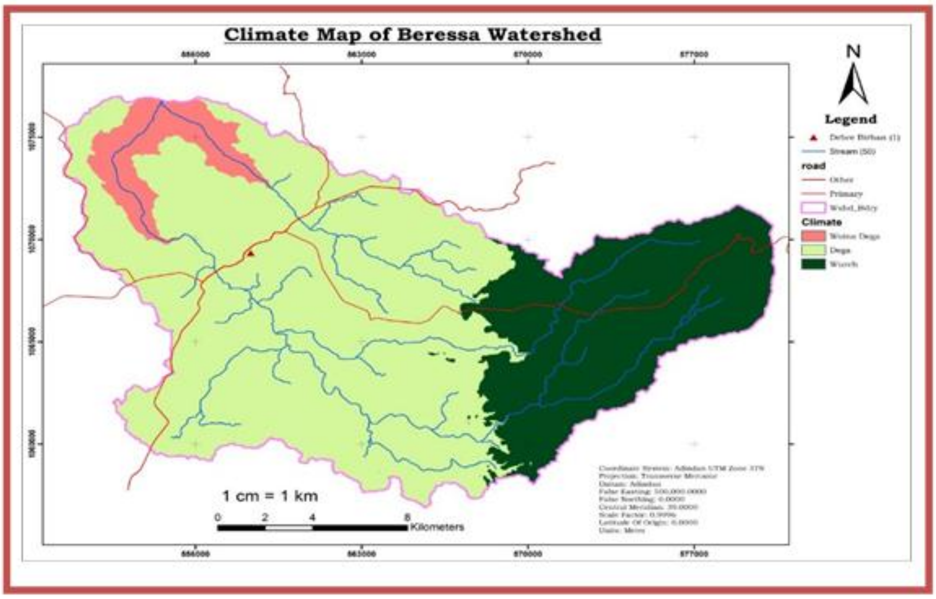

Figure5:Climate map of Beressawatershed

2.5. Land Use Land Cover (LULC)

The LULC of an area is one of the most important determinant factors for the water resource potential of an area. In groundwater recharge, it controls areas of rainfall percolation and runoff generating areas. The LULC data of the area was found from 20m resolution Sentinel- 2 LULC map of Ethiopia.

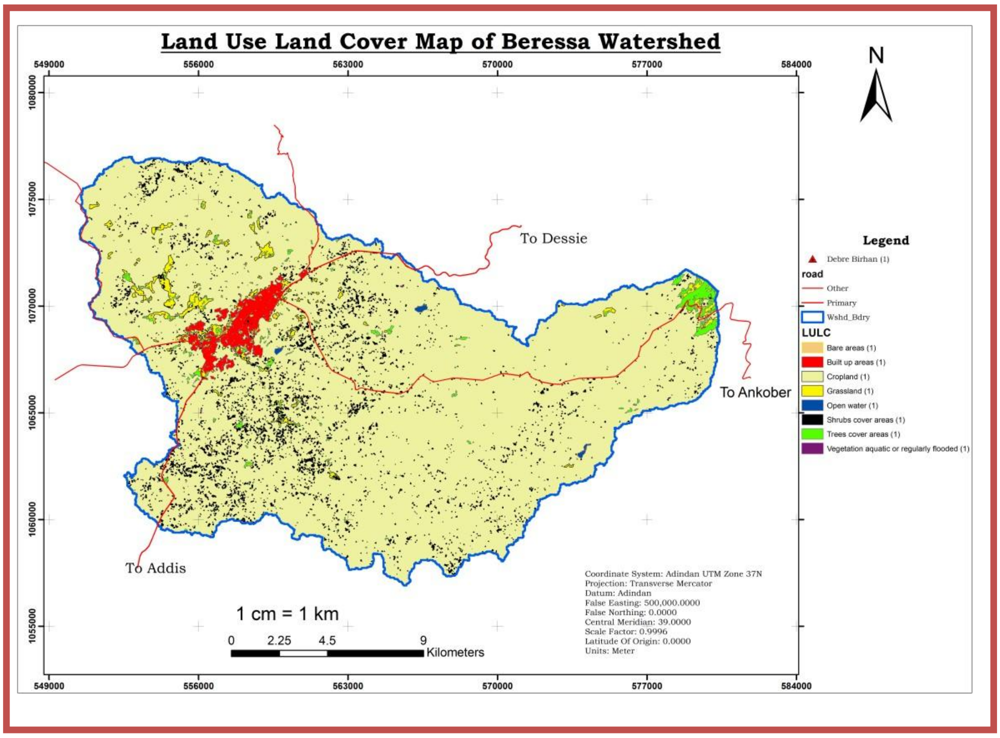

Figure6:LULCmapofBeressa watershed

2.6. Soil

The soil groups of Beressa watershed are classified according to the FAO soil group. As a result, three soil classes are distinctly mapped: VerticCambisols (CMv), EutricLeptosols (LPe) and Lithic Leptosols (LPq). Cambisols holds soils with incipient soil formation. Based on data from (BeleteBerhanu et al., 2013) the hydrologic group of the soils is classified as B and D.

Textureclass	Effective watercapacity(Cw)(mm)	Infiltration rate (f)(mm/hour)	Hydrologic soilgrouping
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 BeleteBerhanu et al., 2013)

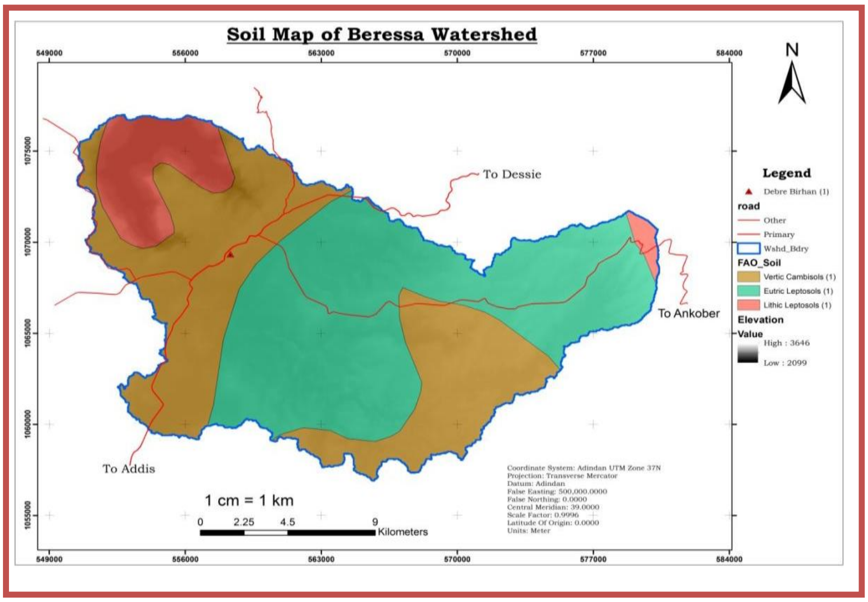

Figure 8: Soil map of Beressa Watershed

III. Geology And Hydrogeology Of Beressawatershed

3.1 GeologyofBeressaWatershed

Beressa watershed is located within the central Ethiopian Plateau along the Northwesternmargin 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 units, which found in the area. To characterize the hydraulic properties of the rocks in the area wehave usedlocalandregionalpreviously workeddata. Accordingly, the area iscovered bythree different lithologicunits, 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.

Sela Dengay-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.

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%andopaqueminerals10percentage.

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. The gradual weathering of the basalt, ignimbrite and rhyolite forms it.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 study,area 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

Inthestudyarea,twosetsofnormalfaultsareobservedasshowninthegeologicalmap.These Normal faults are NE-SW (including boundary faults and several rift oriented stepfaults)andNW-SEtrendingtranscurrentfaults.Intherift-margin,theNE-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^{0}towardsSE)andvertical(trendingNSandN10^{0}E)setofjoints.Iaddition irregularly oriented columnar joint sets (mostly hexagonal faces)are also observedin the ignimbrites and basalts (Jiri Sima, 2018).

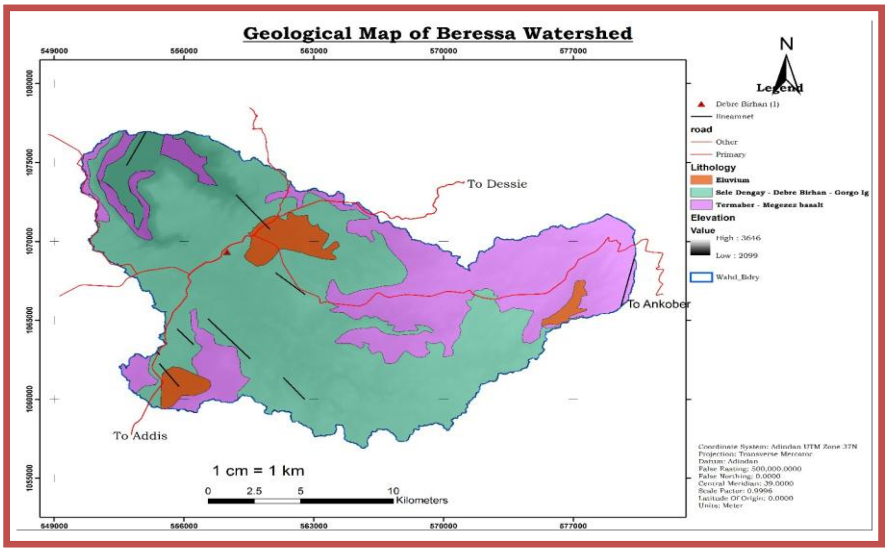

Figure9:Geologicalmap ofBeressawatershed(adoptedfromDanielMesheshaetal.,2013)

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.Reclassifyinglithostratigraphicunitsintohydro stratigraphicunitsrequiresinformationonthehydrauliccharacteristicsofrocks.

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.

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). Itishighlyconsolidatedtoweldedtuffandbeddedwithcolumnar joints, vertical joints, and fractures. 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.

IV. Ground Water Recharge Estimation

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. This method is attractive, because it can be applied almost anywhere precipitation data are available. However, there is a drawback of the water balance method due to shortcomings 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 withinagivenperiodis:

Inputto thesystem-Outflowfromthesystem= Changein storageofthesystem.

Theinflowandout flow,componentsusedin groundwaterestimation includethefollowing:

a) Precipitation

Precipitation is the main input (inflow) component used in the calculation of ground waterrecharge.Isohytes is used to determine the Isohytal area and the average ofthe two consecutiveIsohyetsis used as the precipitation value for that area. Finally, each weighted precipitation is summed up toestimatethetotalaverageannual precipitation oftheareaand its valueis 1146.83m

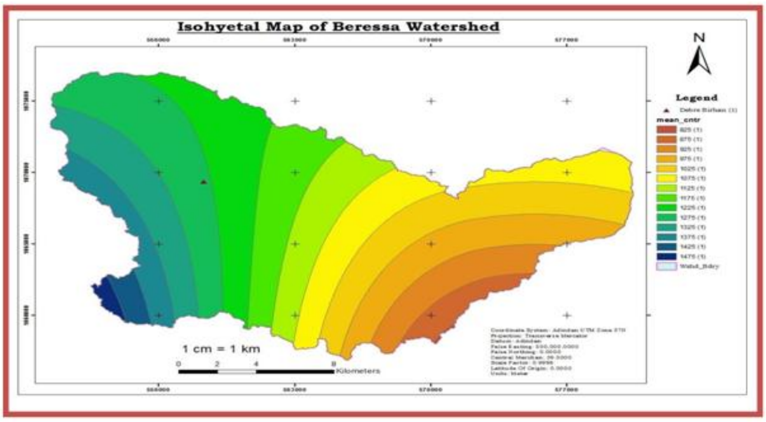

Figure 10: Isohytal map of Beressa Watershed

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**

Table 3: Average monthly precipitation of ten years data (2004 - 2013)

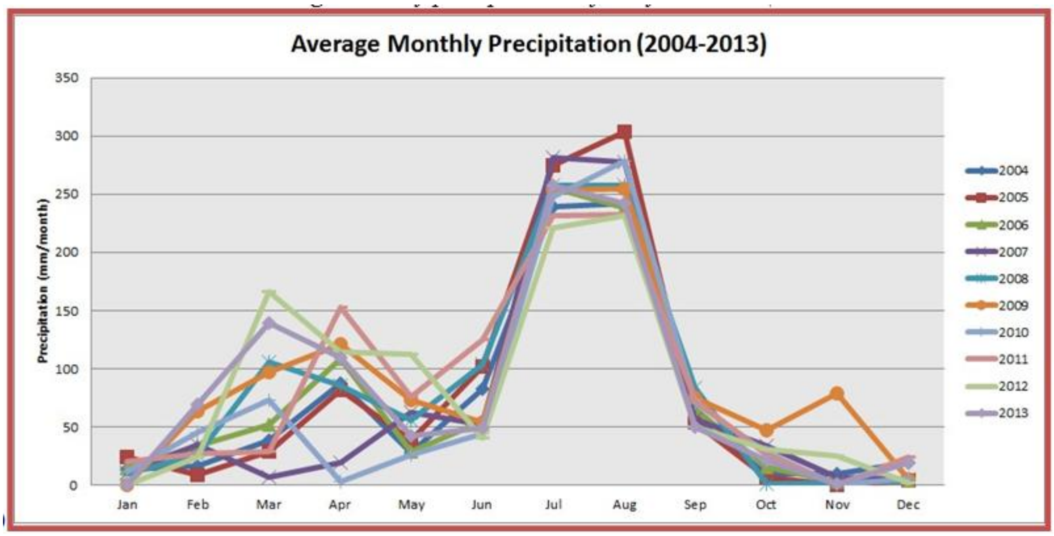

Figure11:Averagemonthlyprecipitation,CFSRdata (2004-2013)

b) Evapotranspiration

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

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 incm/month,*Ta=Mean monthlyairtemperature in (^{O}C),b = latitude correction*

I=annualheat indexUsingtenyearmeanmonthlyairtemperature,theannual heatindex is calculated as;

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

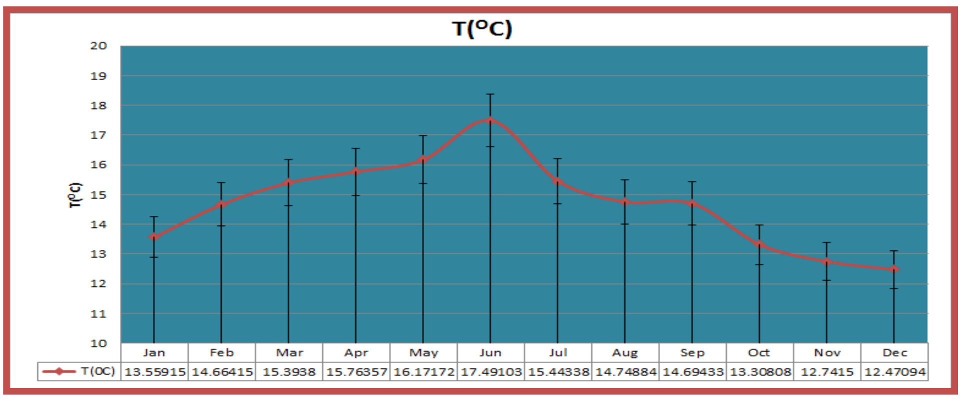

Figure12:AverageMean monthlyairtemperature

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;

$a=0.49+0.0179I-0.0000771I^2+0.000000675I^3$

ThensubstitutingforI,a=**1.44**

The latitude of the study area is approximated to be 10^0 N.

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.

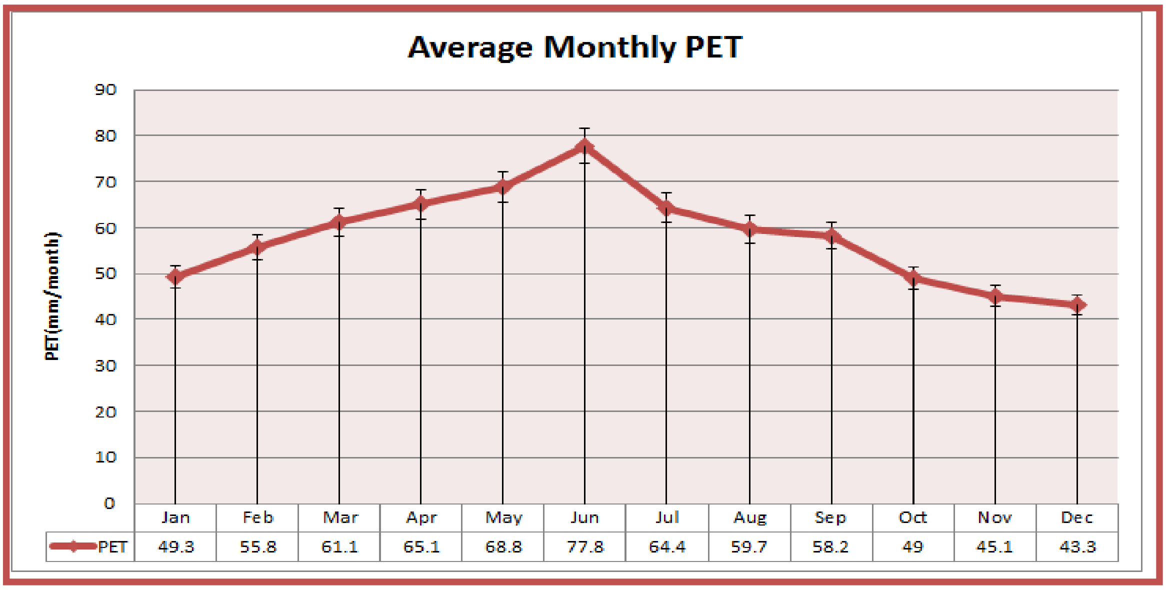

Figure13:Average monthlyPotentialevapotranspiration

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

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

Step 6: Actual Evapotranspiration (AET) - actual evapotranspiration is the sum of availableprecipitation for the month the change in soilmoisture. When Delta is positive, AET

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

=PET.WhenDeltaisnegative,AET=precipitationforthemonth+theabsolutevalueofDelta.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
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	947.44
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	697.60
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 Pot WL	-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	**641.02**

Table5:StepbystepcalculationofActualEvapotranspiration

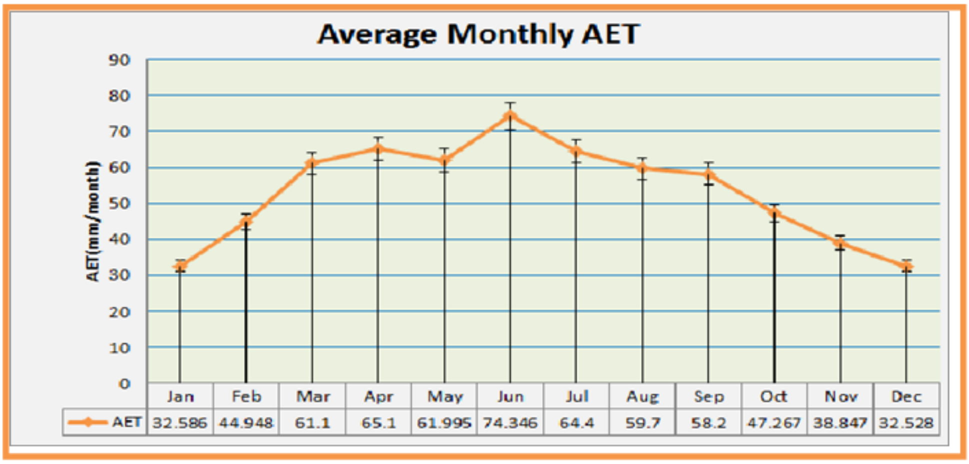

Figure14:Average monthlyactualevapotranspiration

iii. 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.

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 retentionafterrunoffbeginsCN-isknownasCurve NumberassuggestedbytheAmericanSoilConservationService(SCS)
Q- Volume of runoff in inches P-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 using this value potential maximum retention (S) will be;
$S = (1000/86.63) - 10 = 1.54$
$Q = [\sum (Pi - 0.2\times S)\ 2/P + 0.8\times S]/n = 169.655$ mm

iv. Groundwaterrecharge

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)followssurfacepathsas runoff and 14% (136.768mm) of it percolates through the soil layer to replenish the groundwater.

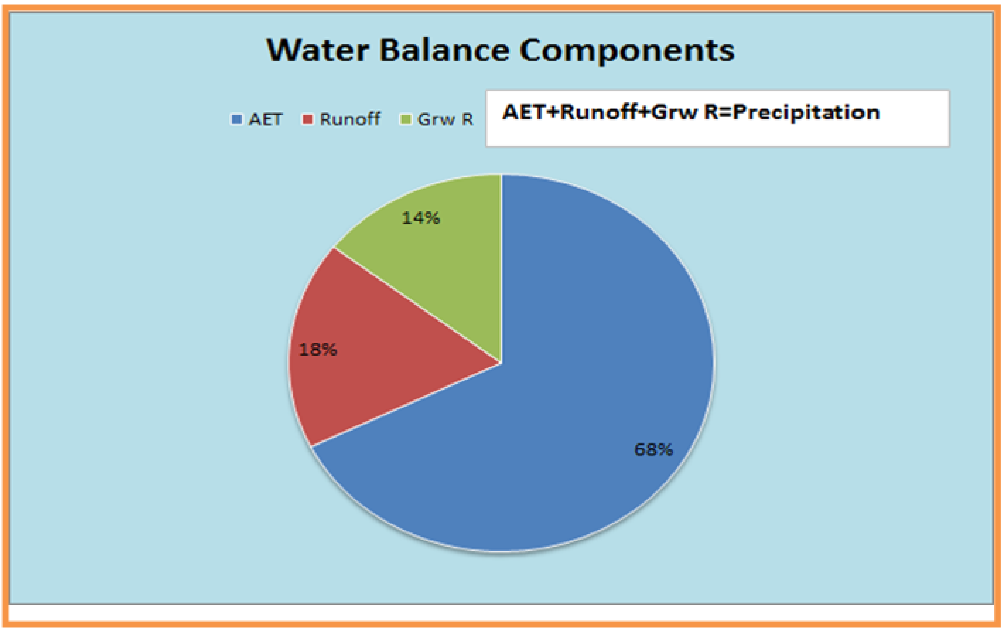

Figure 15: Proportion of the four Water balance components

4.1 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 watershed is divided in to sub-watershed and the sub-watersheds further in to Hydrologic Response Units (HRU). The semi-distributedSWATmodelisbasedonHRUs, w h i c h areformedfromoverlappingmapsforsoil, 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).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 five classes of different slope value ranges. InSWATmodel,PETiscalculatedusingPenman-Monteith,whereasRunoffisestimatedwith Curve Number method. The results obtained based on 10 year monthly averaged valuesofthemodel arepresentedbelow.

Hydrologic Parameter	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Annual*
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*	***1647.8***
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*	***572.4***
Surface Runoff	*0.1*	*0.9*	*10.4*	*21.9*	*7.6*	*13.1*	*69.0*	*86.4*	*17.1*	*0.7*	*1.3*	*0.0*	***228.5***
Inter Flow	*0.5*	*0.5*	*0.9*	*1.3*	*1.4*	*1.3*	*3.6*	*5.9*	*4.8*	*2.8*	*1.5*	*0.9*	***25.5***
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*	***126.5***
Total													***952.9***

Table 7: Average Hydrologic parameters derived from SWAT model

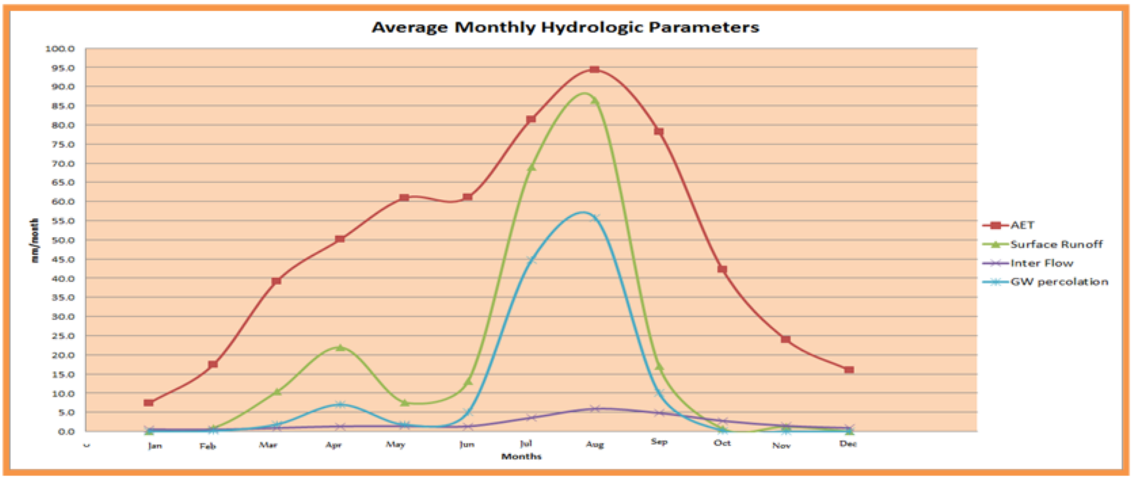

Figure 16: Graph showing average monthly hydrologic parameters calculated using SWAT model

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

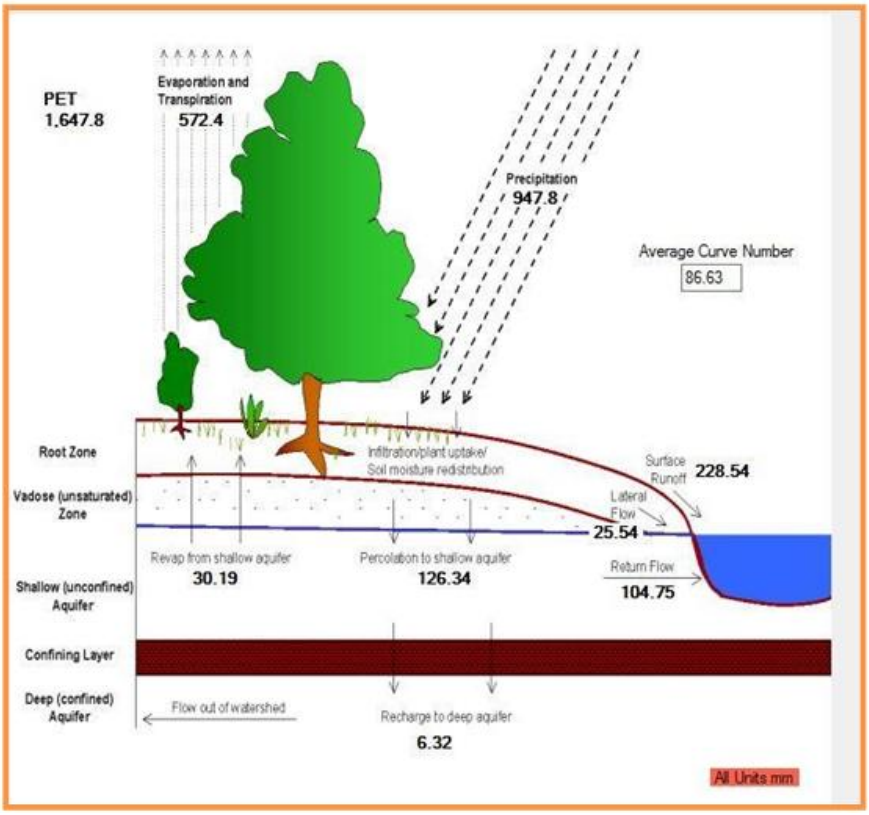

Figure17:AverageannualhydrologiccomponentsobtainedfromSWAT model.

V. DISCUSSIONANDSUMMARY

5.1 Comparison of WBandSWAT Models

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.

5.1 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.

6. Conflicts of Interest

We declare that there is no conflict of interest regarding the publication of this paper.

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