Evaluations of Shallow Groundwater Recharges and Water Use Practices at Robit Watershed

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Abstract. Groundwater resources have a fundamental importance to satisfy the rapidly increasing agricultural, livestock and domesticwater requirements within the region especially in Robit watershed. Hence the quantification of this water resource is important for the efficient and sustainable water resource management. In this study spatial variability of irrigation water requirement, water use (abstractions) and groundwater recharge were estimated for Robit watershed within the eastern part of Lake Tana. Satellite image of Planet Scope on 2nd February 2017 was used to estimate area and type of crops cultivated in the watershed. CROPWAT model has been used to calculate the particular evapotranspiration and water requirement for irrigation using local climatic data. This was calculated for the dominant irrigated crops of Khat (Catha edulis Forsk), hop (Rhamnus prinoides), coffee, tomato and green pepper within the study area. Calibrated QSWAT model was applied to estimate net ground water recharges using local climatic data, soil map, crop management data and derived land use map from satellite image processing. The assessment showed that the entire amount of water applied for irrigation, domestic and livestock purposes was estimated as 1.35 Mm^3/year, 0.02 Mm^3/year and 0.03 Mm^3/year respectively. Net groundwater recharge was estimated as 3.18 Mm^3/year within the watershed. The estimation from the water abstraction survey showed that the total volume of water abstracted within the watershed was estimated as 1.40 Mm^3/year. From the assessment it can be clearly seen that only 44% of ground water resource is extracted annually within the area and there is some potential to expand irrigation areas and the current water usage for various purposes in the future.

Keywords: Water abstraction survey · PLANETSCOPE image · ERDAS IMAGINE · QSWAT · GW recharges · CROPWAT · SWATCUP

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1 Introduction

The spatial distribution of water resources determines the overall performance of any country in different aspects and particularly its economic development. even if it needs detailed researches, based on the present knowledge, water resources in the country are estimated as 30 billion cubic meter (BCM) groundwater, 70 BCM lake water and 124.4 BCM river water resources [1]. These resources are determined in the framework of the rising population and natural aspiration to become and be realized as a developing nation. With fast development and high demands of improved life expectations, Natural resources within the earth faces increasing pressure. Decisions in water management can have social, economic, physical and environmental impact which is wide spread and prevalent. It is essential to possess more appropriate information for having rational decisions for most of the people that leads to have the maximum amount of benefits. Therefore having of consistent and accurate information to the water resources will be an important for the systematic management of resources.

Classification of irrigation areas with best accuracy will help to have better information for the changes in water uses for different seasons. Having such information for the concerned bodies can help to have an improved information of the annual supply and abstractions of the water resource systems. Economic experts will also examine this data together with other socio-economic data to develop scientific knowledge of the aspects of agricultural lands.

Current information on the spatial distribution of irrigated crops in conjunction with temporal variations of the crops could help to have a strategic management of water resource systems [2], using of surveyors for the classification of irrigated land uses are not only time consuming but also tiresome [3] that leads to the problem of getting irrigated land use data with better quality and accuracy. Therefore using remote sensing technologies, that uses a reliable technology and low-priced user costs, to gather estimations for areas under irrigation across a ranges of scale [4]. The satellites of remotely sensed are monitoring the ground continuously, making them compatible for analyzing variations to different scales of irrigated crop lands and understanding water resource management [3]. Remote sensing data can also afford the power to detect the environmental and social influences that subsidizes to observed variations in the watershed.

Majority of models for crops including Cropwat and AquaCrop are point-scale models supported field or plot experimentations and are not consider spatial variations in such factors as irrigation scheduling and practices, crop types and soil characteristics. Therefore, unless such point scale estimates could be up-scaled to the spatial watershed scale, the complete impact of such plot scale investigations cannot be real. Geographic information system is often used to extend their implications to watershed and regional scales through close, embedded loose or close couplings [5]. Therefore, in this study CROPWAT model with GIS software and QSWAT Model have used to compute the effect of land managing practices in Robit watershed (A watershed defined by different crop types, different water resources and with different soil textures.), that can save both operating time and enabled estimates of the spatial pattern of irrigation water requirements and ground water recharges respectively.

2 Materials and Research Methods

2.1 Description of the Study Area

Robit watershed is an experimental watershed with an entire area of 1,412.29 ha located at the north of Amhara region, Bahirdar zuria woreda, Robit bata kebele administration near Lake Tana, the source of Blue Nile River. Robit bata Kebele has a total area coverage of 4,159.62 ha and located 12 km north of Bahir dar town, along the Bahir dar - Gondar asphalt road, it has a sub-tropical ("Woina Dega") climate with average yearly rainfall of 1500 mm, temperature ranges from 11.6 °C to 27.1 °C, and average sunshine hours of 8.0 h. It is a plain with a majority of the catchment area reaching an elevation of 1850 m above mean sea level.

Livelihood system relies on both crop and livestock production and it is one among the potential areas suitable for manual well drilling. Main rain-fed crops grown are finger millet, eragrostis tef, maize and other grains. the area has vast area coverage of the commercial crops like khat (Catha edulis Forsk), coffee, mango and Hop (Rhamnus prinoides) which are the most source of income and irrigated in the dry season and supplementary in the rainy season in cases of long dry spells using both surface and groundwater. Irrigation of those dry season crops are mainly practiced using ground water lifting technologies (i.e. mainly manual water lifting) and motor pumping of surface water when available. Because of the extensive irrigation practices and therefore the large surface water abstractions, Yegasho River dries up in the end of November up to the end of May depending on the rainy season occurrence (Formal interview with local people and Bahirdar zuria agricultural office).

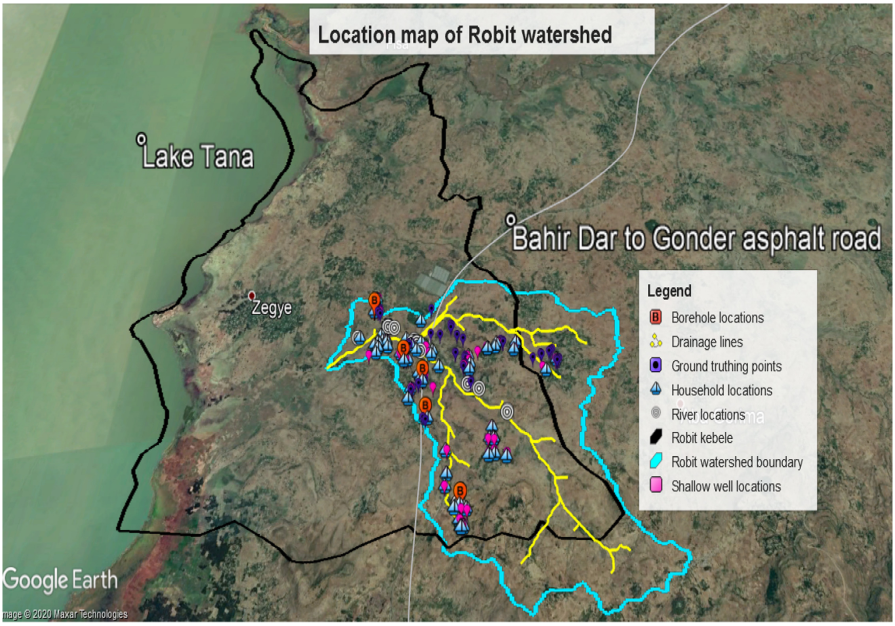

Fig. 1. Location of study area

Because of its close distance to Lake Tana, groundwater potential and experience in smallholder irrigation is comparatively high within the watershed. Shallow groundwater source is the main sources of irrigation water [6] (Fig. 1).

2.2 Remote Sensing Data Processing

The products of PlanetScope images are found in 3 different sources: 1B level PlanetScope image is an image with sensor having radiometric corrections, that is produced for the user with high quality of image processings. 3B level PlanetScope multispectral image is an orthorectified product which is produced to a cartographic projections. 3A Orth Tile PlanetScope image is orthorectified products and can achieve a high variations of uses that require exact geological locations and cartographic projections [7].

A cloudless 3B level PlanetScope multispectral image of Robit Bata watershed has been captured for the mid-season of the irrigated crops on 02/02/2017 in order to differentiate the land use classes accurately (Table 1).

Table 1. Remote sensing data used for LULC classification

ID	Image codes	Date	Spatial resolution
1	20170202_071408_0e2f_3B_AnalyticMS	2/2/2017	3 m

The LULC classification process was achieved following image preprocessing of unsupervised and supervised classifications, conducting accuracy assessment and compilation of Land use land cover and crop area classifications in the watershed.

2.3 River Discharge Data Collection

Stream flow data at Robit watershed outlet was measured from 2015–2018. The river flow at the outlet of Robit watershed from 2015 to 2018 was obtained from innovation Lab for Small-Scale irrigation (ILSSI) project with Bahir Dar University. These data were used in calibration and validation of SWAT model. The flow from 2015–2017 have been used for calibration and the flow for the year 2018 was used for validation.

2.4 Water Abstraction Survey

The water use in Robit watershed is largely defined by the land covers with in the area. The main land use with in the watershed is agriculture, which includes irrigated and non-irrigated crop farming like khat, hop (Rhamnus prinoides), coffee, tomato, green pepper and cultivated lands. Ground and surface water sources within the watershed are used for irrigation, livestock and domestic purposes. The water abstraction survey for the above purposes was surveyed from November 2016–September 2017 for one year which is used to determine the total water abstracted from the study area. For doing a water abstraction survey, a standard questioner was prepared for the collection of domestic, irrigation and livestock water uses in the watershed by the community. On the questioner information regarding to the owner's name, GPS coordinates of sources, actual abstraction assessment, planting and harvesting dates, and frequency of water used days per week. The GPS coordinates had taken directly at the point of abstraction. The water abstraction assessment was an important part of the survey; it was also the most difficult part of the survey. Because during the interview the farmers may increase the number of buckets by desiring awards from government or they may decrease the number of buckets they extract per day by misgiving Taxes.

The abstraction assessment was done by recording the number of buckets the farmers extract per day. Then this volume was multiplied by the time they extract per week. This volume multiplied by the total usage time per year gives the estimated abstracted volume of water per year. The data had been taken from 34 households through ILSSI project.

2.5 Determination of Crop Water and Irrigation Water Requirement

CROPWAT 8 Model has been used to calculate the irrigation water requirements of major crops grown in the watershed. A 10 year average climate data of Bahir dar meteorological station was used because of its proximity to Robit watershed. Although the water requirement of crops and evapotranspiration of crops (ETc) are seems to be the same, water requirement of crops is the quantity of water that needs to be delivered, while evapotranspiration of crops is defined as the quantity of water that must be lost via evapotranspiration. The model calculates (ETc) using Eq. (1). The values for Kc for each types of crops were adopted from [8]. The estimation of irrigation water required for the crops was determined after calculating the effective rainfall by USDA Soil Conservation Service Method [8]. When rainfall is insufficient, therefore in order to meet the water lost by evapotranspiration irrigation is required.

To determine the irrigation water requirement of crops, CROPWAT 8 estimates a daily water balance of the root zone using Eq. (2). To determine the total water requirement of crops at scheme level, the data for irrigated area of each crop type as input to the model should be incorporated that is found from crop map classification.

$$ET_c = K_c \times ET_o \quad (1)$$

ETc - crop actual evapotranspiration crops (mm/day)
Kc - dimensionless coefficient of crops
ETo - reference evapotranspiration of crops (mm/day)

$$IWR = (ETc - ER) \quad (2)$$

Where, IWR - Irrigation Requirement of crops (mm)
ETc - actual Evapotranspiration of crops (mm)
ER - Effective Rainfall (mm)

2.6 Descriptions of QSWAT Model

The water balance components resulted from QSWAT model includes evapotranspiration, infiltration, precipitation, surface runoff, interception, percolation and lateral subsurface flow within the aquifer and the soil profile [9]. Surface runoff has been determined by a modified soil conservation Service (SCS) curve number method [10].

İn the model output the surplus available water after the occurrence of initial abstractions and runoff from surfaces infiltrates inside the soil layer. Within the soil layer Percolation is simulated for every layer. When there is exceeding of the soil water to field capacity, flow of water downwards the soil profile occurs and its flow rate is directed by saturated hydraulic conductivity of the soil. The flow at every soil profile is governed by employing the method of storage routing. Within the soil profile Lateral subsurface flow simultaneously with percolation can be estimated by a kinematic storage routing method using slope length, saturated hydraulic conductivity and slope. Similarly, the water uptake by plants and evaporation from the soil can be estimated by a depth distribution method. Amount of water that undergoes beneath the rock layer by percolation flows into vadose zone before becoming groundwater recharge. When the water in the soil layer exits, exponential decay weighting function can exploited to account the time delay in groundwater recharge. In QSWAT model Ground water is categorized in two: a shallow aquifer and a deep aquifer that water flows to streams within the watershed and outside the watershed respectively. Consequently, groundwater recharge can be divided into shallow aquifer recharge and deep aquifer recharge.

Land Use Map

Using a 3 m by 3 m high spatial resolution planetscope image, a land use map in the year 2017 was classified with best accuracy. Google Earth view of the watershed in 2017 fits correctly and represents all land use classes in the watershed. According to the supervised classification, the most important crops grown in Robit watershed are khat (Catha edulis Forsk), hop (Rhamnus prinoides), coffee, tomato, green pepper, and cultivated lands. Especially Khat, Coffee, and Hop are being cultivated in the watershed throughout the year. In recent years even if the Ethiopian government planned to avoid khat and replaced it with other crops, but more and more farmers are cultivating khat. Khat is a valuable product for local people and for export purposes. As a result, it is a basic source of income for local peoples in the area. Mango trees are also cultivated in the area and during the classification process; they were considered to be dense forests based on their reflectance values.

The plant characteristics of the crops khat and hop have been replaced by plant characteristics of coffee due to lack of known parameters in SWAT 2012 database.

Soil Map and Data

The soil map used in this research was Africa Soil Information Service (AFSIS) that is downloaded from https://www.isric.org/projects/soil-property-maps-africa-250-m-resolution. AFSIS soil summary with its database file and areal coverage is used for the definition of each HRUs in the watershed. Based on its spatial distribution there are nine different soil types in the watershed as shown in Fig. 2 (Table 2).

Weather Data

The daily weather data used in the model are minimum and maximum temperature, solar radiation, precipitation, relative humidity and wind speed data. Angstorm-Prescott equation was used to estimate solar radiation by using daily sunshine hour by relating short-wave radiation with other physical factors, as optical air mass, turbidity, and

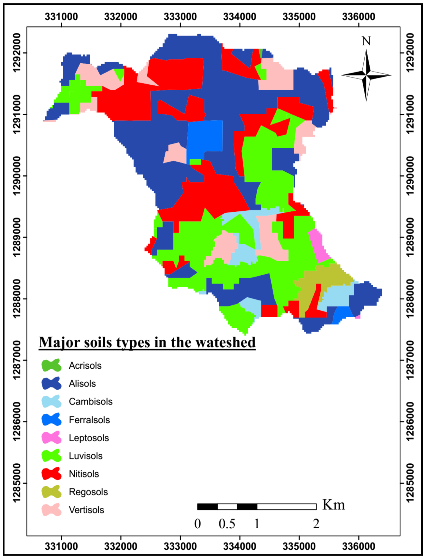

Fig. 2. Soil map of Robit watershed

Table 2. Percentage of major soil coverage in the watershed

FID	Major soils	Area	Percent coverage
1	Acrisols	0.67	0.05
2	Alisols	494.30	35.00
3	Cambisols	56.99	4.04
4	Ferralsols	40.02	2.83
5	Leptosols	10.79	0.76
6	Luvisols	335.70	23.77
7	Nitisols	320.52	22.70
8	Regosols	37.05	2.62
9	Vertisols	116.25	8.23
Total		**1412.29**	**100**

extraterrestrial radiation, water vapor content of the air and type and amount of cloud cover [12].

The daily metrological data from 1993–2018 were obtained from Bahir Dar meteorological service. Bahir Dar station weather data was used for this study as Robit watershed is located 12 km from the station and it has the same topographic and climatic characteristics. The WGEN uses average monthly meteorological data as aparameters for long period of yeras. The weathe generator data can also be prepared for QSWAT model using independent techniques such as dew.exe for dew point temperature and pcpSTAT for rainfall [13].

İn QSWAT weather generator model is incorporated to fill missing weather data during recordings. Missing weather data are left as it was in name.dbf format and a value of −99.00 inserted for missed values. QSWAT understands these values to generate weather data for that missed data at that day.

Model Sensitivity Analysis

The capability of the model to simulate water balance components sufficiently could be tested by using global sensitivity analysis, calibration and validation of the model [15].

For this study sensitivity analysis was performed in the model using the data from (1993–2018) and for the entire observed river flow data from (2015–2018).

Sensitive parameters were selected by studying previous calibration parameters and documents and from SWAT manual and researches done in the nearby watersheds e.g. [16–18].

SWAT Model Calibration
Automatic model calibration was done by SUFI-2 (Sequential Uncertainty Fitting version 2) which is a SWAT-CUP interface. SWAT-CUP is a separate uncertainty and calibration program established by [19] and SUFI-2 is a procedure for uncertainty and calibration analysis [20] as proposed by [21], SUFI-2 gives better results when compared with other programs even for small number of simulations.

To evaluate the performance of the model statistical and graphical techniques have been used. [14] recommended three model performance indicators from different statistical model evaluation methods. The dimensionless Nash-Sutcliffe efficiency (NSE) [22] measures normalized magnitude of the variances between measured and simulated flow. Values of NSE varies from −1 to 1. NSE of 1 shows the exact fit between simulated and observed flows. The value of NSE less than zero shows unacceptable performances.

The second performance indicator is PBIAS (percent bias). PBIAS shows the average variations between measured and simulated flows. PBIAS value of zero shows exact similarity; negative value shows overestimations and positive value shows underestimations of the model. R^2 (regression coefficient) describes the proportion of the total variance in the observed flow which could be clarified by the model. When the value of R^2 approaches to 1, there is high agreement between measured and simulated flows.

SWAT Model Validation
Validation of measured Yigashu River flows was done using an autonomous set of data without any adjustments of the calibrated parameters. The process continued till simulation of validation-period stream flows confirm that the model performs satisfactorily.

For this study, measured Stream flow data at the outlet of Yigashu River from 2017 to 2018 was used for the validation techniques to evaluate the model accuracy.

3 Results and Discussion

3.1 Land Use Map of the Study Area

Once the classification was completed, the land use land cover map of the study area was prepared and actual irrigated crop areas for Robit watershed was masked from this map as shown in Figs. 3 and 4.

The land use classes with their areal coverage is shown in Table 3 and this classification was used for HRU definition in SWAT modeling since overall accuracy and kappa coefficients are greater than 85%.

Table 3. Area of each land cover

FID	Class name	Area (ha)	Percent coverage
1	Khat (Catha edulis Forsk)	81.17	5.75
2	Hop (Rhamnus prinoides)	39.57	2.8
3	Coffee	2.56	0.18
4	Tomato	46.46	3.29
5	Green pepper	13.89	0.98
6	Cultivated land	1000.59	70.85
7	Dense forest	33.43	2.37
8	Eucalyptus trees	62.05	4.39
9	Farm village	45.37	3.21
10	Grazing land	63.47	4.49
11	Road	19.53	1.38
12	Shrub land	4.17	0.3
Total Area		**1412.29**	**100**

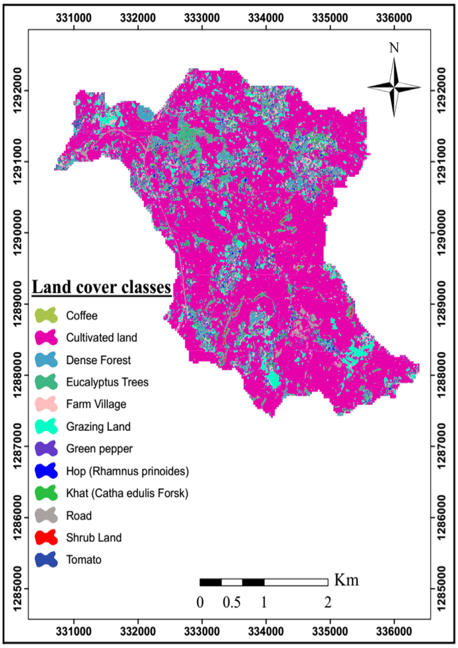

Fig. 3. Land use land cover map of Robit watershed

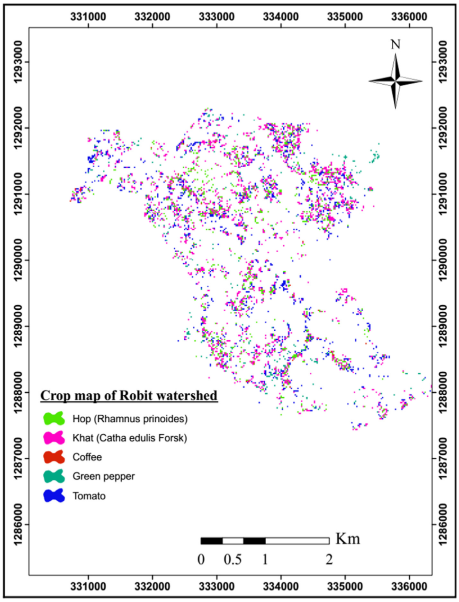

Fig. 4. Irrigated crop map of Robit watershed

3.2 Sensitivity Analysis

For sensitivity analysis twenty two flow parameters were tested by the default parameter values of upper and lower bounds. During the test analysis twelve of them have found to have higher effects on stream flow simulation. The selected parameters during sensitivity analysis were used for the process of calibration. A full clarifications of the parameters has been given in SWAT manual [14].

3.3 Calibration and Validation QSWAT Model

Model Calibration Results

The model was simulated for a 26 data years from 1993 to 2018 with three years of warm up periods (1993–1995). The measured stream flow data of the period from 2015 to 2017 were used for calibration and the data for these years were selected based on the measured data availability. Monthly observed data and simulated results comparison were used during the analysis calibration was simulated until the results for the performance indicators have reasonable values (Table 4).

Table 4. Calibrated values of flow parameters

Parameter name	Unit	SWAT default value	Fitted value	Calibrated parameter value
1:R__CN2.mgt	–	91	−0.08	83.53
2:V__GW_REVAP.gw	–	0.02	0.34	0.34
3:A__GW_DELAY.gw	days	31	−2.31	28.69
4:A__GWQMN.gw	Mm	1000	1704.15	2704.15
5:A__CANMX.hru	mm	0	1.06	1.06
6:V__ESCO.hru	–	0.95	0.61	0.61
7:V__CH_N2.rte	–	0.01	0.74	0.74
8:V__RCHRG_DP.gw	fraction	0.05	0.09	0.09
9:V__ALPHA_BF.gw	days	0.05	1.28	1.28
10:R__SOL_AWC.sol	mm/mm	0.12	0.18	0.14
11:R__SOL_K.sol	mm/h	2.08	0.29	2.68
12:A__REVAPMN.gw	Mm	750	153.12	903.12

Note: from the above Table 4, R (relative) stands for multiplying initial parameter by (1 + a given value). V stands for Replacement of initial parameter by calibrated value. A (absolute) stands for adding or subtracting calibrated parameter value to the original value.

Parameter Value Evaluations

Twelve flow parameters were processed during automatic calibration and their parameter values were iterated with permissible ranges until best agreements between simulated results and measured flow data was found.

It is significant to look for what extents the default parameter values established for the USA conditions were familiarized towards African conditions in the calibration process. Great attentions should be given for the calibrated parameters where unrealistic results may come from wrong parameter values. These parameters manage processes which result in a water loss from the system. The SCS curve number for moisture condition II (CN2) is related with permeability of the soil land use classes and antecedent soil water conditions. Groundwater "revap" coefficient (GW_REVAP) is the process of capillary rise, but somewhat the equation clarifies evapotranspiration from the shallow aquifer which is determined by the reference evapotranspiration. The volume of "revap" water is not passing to the soil surface, but it may lost from the system and should not be excessively high. Soil evaporation compensation factor (ESCO) is integrated to permit the user to adjust the depth distribution used to fulfill the soil evaporative request to account for the influences of capillary actions; it ranges from 0 to 1. When the value decreases, the model can extract more of evaporative demands from lower levels.

The fraction of Deep aquifer percolation (RCHRG DP) simulates the water that passes to deep aquifers that will not discharge towards the river. Such water losses to deep aquifer losses may be important in small catchments. Base flow alpha factor (ALPHA_BF) shows groundwater flow response to changes in recharge. Values changes from 0.9 to 1.0 for land with a fast response and values from 0.1 to 0.3 for lands with low responses to recharge. The time delay (GW_DELAY) can be defined as the required time for water escaping from the lower part of the root zone to enter the shallow aquifer and threshold depth of water in the shallow aquifer required for return flow to occur. (GWQMN) is a threshold depth in the shallow aquifer, and recharge will occur when the aquifer level goes outside GWQMN. As QSWAT model may start with an empty shallow aquifer, it may take many years before the GWQMN level is reached. In that situation, the model will start flow of water in the shallow aquifer whereby the rainfall will not matched with the output flows and losses.

GW_REVAP is a coefficient which determines revap flows. revap flow may not be occur, if GW_REVAP is null and revap will be potential evapotranspiration when its value is 1. GW_REVAP ranges from 0.02–0.20. Maximum canopy storage in mm of H2o (CANMX) will exactly influence surface runoff infiltrations and evapotranspiration. As rain falling, the interception canopy reduces the erosive energy of droplets and apportion of rainfall is trapped within the canopy (Figs. 5 and 6 and Tables 5 and 6).

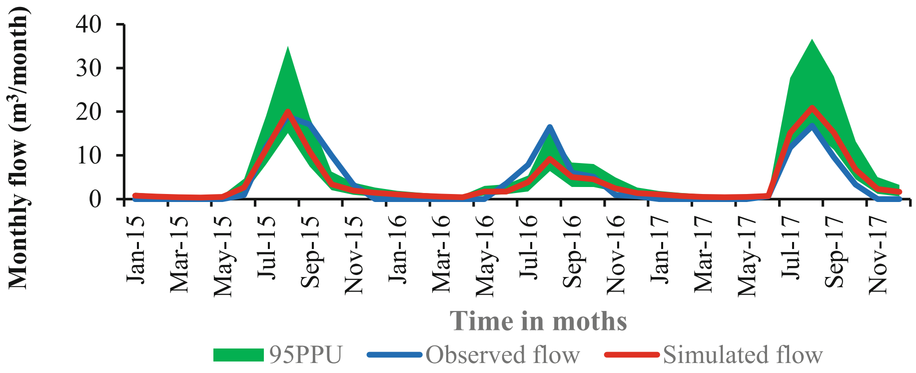

Fig. 5. Hydrograph of the observed and simulated monthly flows for the calibration period at the outlet of Robit watershed

Table 5. Calibration statistics for measured and simulated flows at Robit watershed

Calibration period	R^2	NSE	PBIAS	p-factor	r-factor
Jan 2015–Dec 2017	0.80	0.80	−5.4%	0.28	0.75

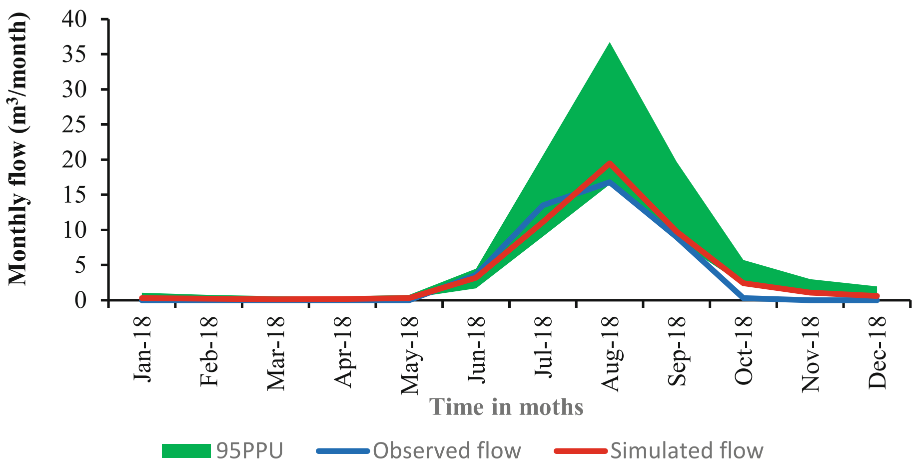

Fig. 6. Hydrograph of the observed and simulated monthly flows for the validation period

Table 6. Validation statistics for measured and simulated flows at Robit watershed

Validation period	R^2	NSE	PBIAS	p-factor	r-factor
Jan 2018–Dec 2018	0.96	0.95	−12.9	0.33	0.43

3.4 Spatial Variability of Irrigation Water Requirement

Net Crop water requirement and irrigation requirement has been estimated for the crop lands in the area for the 2016/2017 cropping season. The crop coefficients listed in CROPWAT model were used to estimate the water requirements of major crops at each growth stages. For the irrigated crops with in the watershed the result of the CROPWAT model is presented as shown in Table 7.

Table 7. Results of net and gross irrigation requirements of crops with-in the area

Crop	Area (ha)	NIR (mm/season)	NIR (Mm^3/season)	Irrigation efficiency (%)	GIR (Mm^3/season)
Khat	81.17	935.6	0.76	0.7	1.09
Hop	39.57	714.7	0.28	0.7	0.40
Coffee	2.56	806	0.02	0.7	0.04
Tomato	46.46	360.4	0.17	0.7	0.34
Green pepper	13.89	271.7	0.04	0.7	0.08
Total	183.65		1.27		1.95

The total irrigation water requirement for each crop types for the 2016/2017 cropping season was calculated as:

$$IR_{total} = IR_{khat} * \frac{A_{khat}}{A_{total}} + IR_{hop} * \frac{A_{hop}}{A_{hop}} + IR_{coffee} * \frac{A_{coffee}}{A_{total}} + IR_{tomato} * \frac{A_{tomato}}{A_{total}} + IR_{greenpepper} * \frac{A_{greenpepper}}{A_{total}}$$

3.5 Estimation of Water Used for Irrigation

From the water abstraction survey the volume of groundwater abstractions for irrigated crops was calculated for the whole irrigation season. The depth of irrigation water was calculated by dividing the total volume of water abstracted from a shallow well by the area of each crop type with in the watershed. The actual water that the farmer applied for each crop was compared to the theoretical value of CROPWAT results.

The information presented in the table below, show the actual quantity of irrigation water applied in terms of volume and depth of irrigation and irrigated area in Robit watershed and the CROPWAT result (Table 8).

Table 8. Comparison of applied irrigation and theoretical irrigation water requirements

Crop type	Area (ha)	Irrigation applied per season (mm)	Irrigation applied per season (Mm^3)
Khat	81.17	620.74	0.50
Hop	39.57	786.10	0.31
Coffee	2.56	344.69	0.01
Green pepper	13.89	961.97	0.13
Tomato	46.46	837.55	0.39
Sum	183.65		1.35

3.6 Estimation of Water Used for Livestock

Livestock production was found to be primarily dependent on groundwater for all or part of the watershed. Multiple numbers of livestock data was collected from Robit Kebele agriculture office. For these multiple animal types the water used per livestock per day was also collected by interviewing with model farmers in Robit kebele. Water used was calculated for each animal type by multiplying the average water used per livestock per day by the number of days used in the study year as indicated in Table 9. As the information obtained from the questioner, the farmer use hand dug wells for livestock for months starting from November to May, which counts 210 days. The total volume of water abstracted for livestock consumption was 25,840.29 m^3 per year at the watershed level. There are also unaccounted water (water loses) due to overflow of containers, illegal water usages, in accuracies in counting of the number of buckets used and over use of water for emergencies and ceremonies. As a result of these uncounted water uses 15% loss is adopted from [24]. Therefore the annual livestock water abstraction becomes 29,716.33 m^3. The total area of the watershed used for ground water storage was estimated as 1412.29 ha, and the annual equivalent depth for livestock consumption represents approximately 2.1 mm per year. The total water demand for livestock purposes based on single livestock demand specified in the ministry of water resources guideline is 47,737.31 m^3. So that as clearly seen from Table 9 the volume of water they abstracted for livestock consumption is less than the amount of water calculated based on [24].

Table 9. Water used and water demand computations for different animal types in the watershed

Livestock type	Number	Average water used/Live stock (L)	Total water used (m^3)	Water demand/ Livestock/day (L)	Total water demand (m^3)
Cow	998	30	6,287.40	50	10,479.00
Ox	1200	35	8,820.00	50	12,600.00

(*continued*)

Table 9. (*continued*)

Livestock type	Number	Average water used/Live stock (L)	Total water used (m^3)	Water demand/ Livestock/day (L)	Total water demand (m^3)
Bull	452	25	2,373.00	50	4,746.00
Heifer	564	25	2,961.00	50	5,922.00
Calf	474	10	995.4	10	995.4
Sheep	686	8	1,152.48	10	1,440.60
Goat	102	8	171.36	10	214.2
Donkey	476	30	2,998.80	50	4,998.00
Mule	11	35	80.85	50	115.5
Water loses	(15%)		3,876.04		6,226.61
Sum			**29,716.33**		**47,737.31**

3.7 Estimation of Water Used for Domestic Purposes

The population data at each village was collected from Robit Kebele agriculture office for the year 2017. The daily average domestic water consumption per person for a single person was estimated as 55 L for five households which corresponds to 11 L per capita per day. And the amount of water abstracted from ground water for domestic purpose in terms of volume was estimated as 13,546.61 m^3 per year. There are also unaccounted water (water loses) due to overflow of containers, illegal water usages, in accuracies in counting of the number of buckets used and over use of water for emergencies and ceremonies. As a result of these uncounted water uses 15% loss is adopted from [24]. Therefore, the annual domestic water abstraction becomes 15,578.60 m^3. The total area of the watershed used for ground water storage was estimated as 1412.29 ha, and the yearly equivalent depth of water for domestic use shows around 1.10 mm per year.

Table 10. Water used and water demand computations for domestic purposes in 2017

Sex	Number	Average percapita water consumption in liters	Domestic water used (m^3)	per capita water consumption (L)	Domestic water demand (m^3)
Male	1694	11	6,801.41	25	15,457.75
Female	1680	11	6,745.20	25	15,330
Water loses (15%)			2,031.99		4,618
Sum	**3374**		**15,578.60**		**35,405.91**

Generally as clearly seen from Table 10 the volume of water they abstracted for domestic use is less than the amount of water calculated based on [24].

3.8 Estimation of Total Water Abstractions for the Watershed

The total water abstraction is the sum of water abstracted for irrigation, livestock and domestic purposes with-in the watershed. The volume of water abstracted for irrigation, livestock and domestic uses is calculated as 1.40 Mm^3/year (1.35 Mm^3/year + 0.02 Mm^3/year + 0.03 Mm^3/year) (Fig. 7).

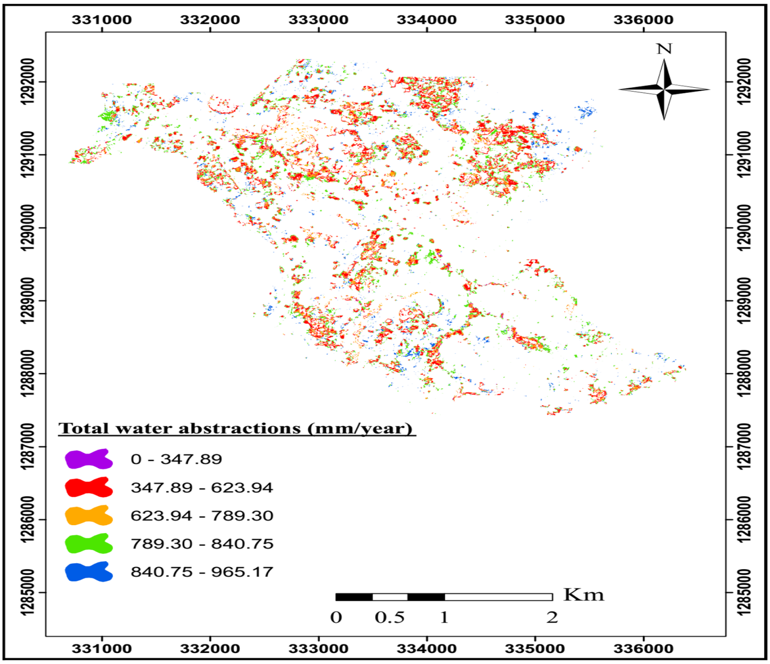

Fig. 7. Spatial variations of total water abstractions at Robit watershed

3.9 Base Flow (Return Flow)

Base flow (Return flow) is the quantity of stream flow come from groundwater. QSWAT segments groundwater into two systems of aquifers: a shallow unconfined aquifer, that create base flow to streams within the watershed, and a deep confined aquifer, that contributes base flow to streams outside the watershed. Water percolating beyond the bottom of the root zone separated into two parts each part becomes recharge for one of the aquifers. The return flow of water which arrives the main channel for Robit watershed is used for different purposes especially for irrigation purposes from November up to the end December and the spatial variability of base flow from QSWAT model is presented in Fig. 8. The average annual base flow obtained from the calibrated QSWAT model for the whole watershed area of 1412.29 ha was estimated to be approximately 1.37 Mm^3/year.

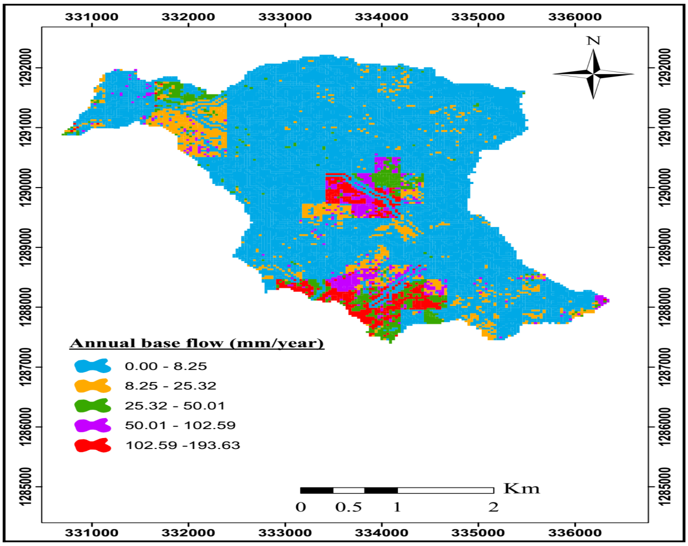

Fig. 8. Spatial variations of simulated base flow

3.10 Availability of Groundwater Recharge

A major determining factor of groundwater storage, groundwater table and thus groundwater resource estimation is the recharge. The groundwater recharge is essential in ascertaining the sustainability of withdrawals and for efficient management of groundwater resources. QSWAT model gave an indication of the spatial and temporal variation of this recharge, with respect to properties of the overlaying soil cover.

The average annual groundwater recharge obtained from the calibrated QSWAT model with in the watershed area of 1412.29 ha was estimated to be approximately 4.55 Mm^3/year. The detail recharge at each hydrologic response unit is presented in the appendices section. The spatial variations as shown in Fig. 9 shows a clear spatial pattern with a significant difference reflecting the great differences in land use and soil characteristics with in the watershed.

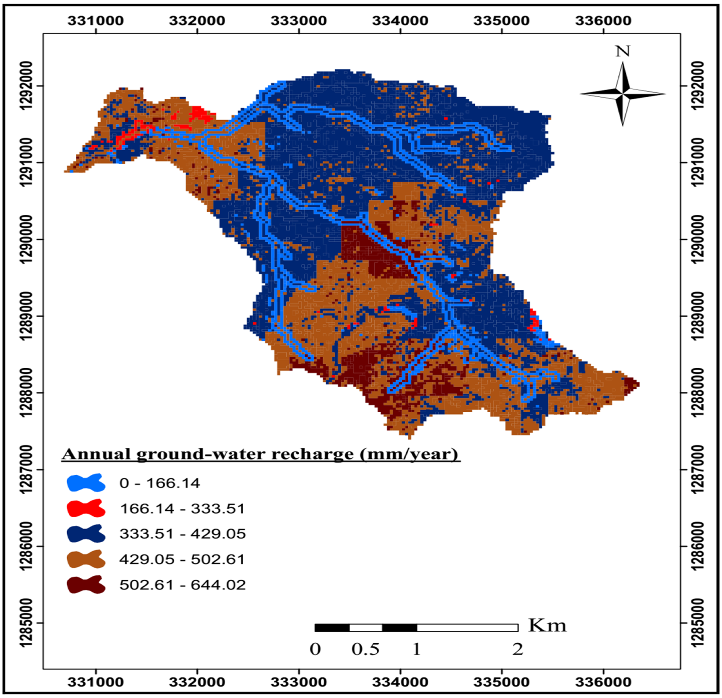

Fig. 9. Spatial variations of simulated groundwater recharges

3.11 The Interaction of Ground Water Use and Availability

See Table 11.

Table 11. General information about water use and availability of groundwater recharges within the watershed

Description	Amount
Watershed area (ha)	1,412.29
Area of irrigated crops (ha)	183.65
Percentage of irrigation area from total watershed area (%)	13
Water abstractions for irrigation purposes (Mm^3/yr)	1.35
Water abstractions for domestic purposes (Mm^3/yr)	0.02
Water abstractions for livestock purposes (Mm^3/yr)	0.03

(*continued*)

Table 11. (*continued*)

Description	Amount
Total Water abstractions for all purposes (Mm^3/yr)	1.4
Water demand for domestic purposes (Mm^3/yr)	0.04
Water demand for livestock purposes (Mm^3/yr)	0.05
Irrigation requirements (Mm^3/yr)	1.95
Total water demand for all purposes (Mm^3/yr)	2.04
Total groundwater recharges (Mm^3/yr)	4.55
Base flow (Mm^3/yr)	1.37
Net groundwater recharges (Mm^3/yr)	3.18
Percentage of total water abstractions from total recharge (%)	44
Percentage of total water demand from total recharge (%)	64.2
Level of groundwater exploitations	Underexploited

3.12 Discussions and Comparison of the Current Study with the Other Studies

Understandings on hydrological processes is the crucial element in water resource development and management programs. Watershed based hydrologic simulation models are used for the evaluations of the volume of water. QSWAT model was applied and was successfully evaluated through sensitivity analysis, model calibrations and model validations. Subsurface flow parameters were more sensitive to stream flows of the study area, showing the area has good recharge capacity.

QSWAT model has been found to obtain a reliable estimations of annual recharge for Robit watershed that was confirmed with different model performance measures. As a result, the calibrated parameters can be considered for further hydrologic analysis of the watershed. The QSWAT model can also considered as a potential model for the processing of the hydrology of ungauged watersheds in mountainous areas, which may have similar hydrological and meteorological characteristics with Robit watershed.

Model efficiency values were similar to those found by [25] using SWAT for monthly stream flow. In order to calibrate the water balance components of the watershed they used observed long-term stream flow data of the nearby watershed of Gumara river flow to calibrate the SWAT model. In their study Observed stream flow data from 1994–2016 of Gumara river was used for the calibration of SWAT model using Sequential Uncertainty Fitting program under the Uncertainty Procedures (SWAT-CUP) and found a Nash Sutcliff efficiency (NSE) of 0.80 and Percent Bias (PBIAS) of 5.4% which fits with the ongoing study. In this study the annual recharge varies spatially from 247 mm to 317 mm. this result has some variations with the ongoing study and this variations come from input data variations of SWAT model such as land use data soil database and stream flow data.

On the other hand, [26] estimated the annual recharges (interflow + base flow) by the Thornthwaite method and found 477 mm in 2014 and 344 mm in 2015. In their study when they only considers the part of the watershed with deep soils layers which is 52% of the watershed, the recharge to the aquifer was obtained as 933 mm/year in 2014 and 667 mm/year in 2015.

4 Conclusions

Water resources are the fundamental portions of life, therefore in order to upgrade their usage, wise planning, utilization and proper management is vital in the twenty-first century. In that case, the expansion of applications of GIS and remote sensing methods make the assessment and water resource modeling effective and easy for such purpose. QSWAT model that is an open access model for groundwater recharge estimation is based on hydro-meteorological and biophysical characteristics and it is essential to estimate long-term average yearly groundwater recharge in annual and seasonal basis for proper utilization, wise management and future planning of water resource systems.

In this study applying high resolution planetScope images for land use and crop area classification is simple and gives acceptable results with reasonable accuracy.

The model has been calibrated for the years of 2015–2017 and validated for year 2018.The value for NSE and R^2 for calibration (2015–2017) were 0.80 and 0.80 respectively. For validation (2018), NSE and R^2 are 0.95 and 0.96 respectively. These values show that model results are good and estimated net recharge values are reliable.

The assessment of the spatial variability of irrigation requirements in Robit watershed indicates that it increases spatially from 271.7 mm/year to 935.6 mm/year by considering an irrigation efficiency of groundwater as 70% at the watershed level.

The annual net recharge was estimated by subtracting the water abstraction surveyed in 2016–2017 from the total groundwater recharge and the annual average water abstraction was 44% of the annual average net recharge contribution during the study period and this result shows that there is high potential of groundwater recharges in the area.

Generally, the study indicates that there was enough water in the watershed even during the dry time and from the spatial map of the water abstraction survey the farmers apply less water than the crops require.

Finally this study provides evidence for the first time to link size of land parcels and the water use practices within the area and the available groundwater recharges.

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