Evaluation of Shallow Ground Water Recharge and Its Potential for Dry Season Irrigation at Brante Watershed, Dangila, Ethiopia

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Abstract. The estimation of crop water demand and understanding groundwater use is an essential component for managing water effectively. Groundwater is the main source of irrigation in Dangila. However, there is a lack of information in the study area on amount of irrigated land, irrigation water use and demand, groundwater recharge. Consequently, the objective of this study is to determine the groundwater recharge and its potential for dry season irrigation. The study was conducted in Brante watershed of 5678 ha located in Dangila woreda, Ethiopia. Water table data from twenty-five wells and discharge data at the outlet of the watershed used to assess recharge amount in 2017. To calculate irrigation water demand, CROPWAT model was used. Questionnaires were undertaken to assess groundwater use. A KOMPSAT-2 image was used to map shallow groundwater irrigated vegetables in February 2017. From the soil water balance method, the annual groundwater recharge was 17,717,690 m^3 which is 15.8% of annual rainfall, and recharge amount of 14,853,339 m^3 was obtained using water table fluctuation method. From satellite image classification the area coverage of dry season irrigated vegetables (onion, tomato, pepper) below the main road was 4.02 ha. From CROPWAT result, seasonal irrigation water demand for onion, Tomato, and pepper was 333,314, and 261 mm respectively. However, the questioners result indicates that farmers apply in average 20% more water than crop water demand. In the watershed 60,150 m^3, 62,750 m^3 and 41,603 m^3 of water was abstracted for irrigation, domestic and livestock use respectively. The ratio of groundwater use to groundwater recharge at the watershed scale was found to be only 1%. This study indicates that the current use of groundwater was sustainable. For better improvement of household livelihood irrigation can be further expand using ground water. Future work should be performed to determine if the method outlined in this research could be used to accurately estimate available water potential.

Keywords: Recharge · Brante watershed · Water balance · Ethiopia

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1 Introduction

1.1 Background

Irrigation is practicing virtually all over the world, at scales ranging from subsistence farming to large scale national enterprise [1]. Groundwater consider as the main source of water for meeting irrigation, livestock and domestic uses. The driving factors for groundwater use are; its long period of time in the ground, the storage capacity is maximum; level of contamination is low, wide distribution and availability within the reach of the users [2–5]. Groundwater is the worlds most extracted and fresh raw material with withdrawal rates currently estimated to be 1000 cubic kilometers per year [6].

The quantity of water that is extracted from an aquifer without causing significant depletion is primarily dependent on recharge amount and thus, quantification of groundwater recharge using scientific principles is pre-requisite for efficient management of water resource [7–9].

Accurate estimation of crop water demand is an essential component for managing water resource effectively [10]. However, the estimation of the crop water demand requires data on irrigated areas, types of crops grown and cropping calendars. Understanding household groundwater abstraction is important for efficient and effective water resource management [11]. Comparison of actual crop water use against the theoretical irrigation demand is an essential component of irrigation scheduling [12]. The sharper increase in food demands as a result of population pressure and frequent drought has revealed the importance of irrigation development in Ethiopia. Groundwater irrigation is being prioritized recently as the best alternatives for reliable and sustainable food security, income generation, livelihood improvement in the country [13].

With an extended dry season, consumptive water use generates a demand for irrigation in excess of the availability of groundwater. In some cases, inappropriate irrigated agriculture exploits non-renewable groundwater resources or very weakly recharged aquifer systems. The ability to make sound and effective decisions is hampered by a lack of reliable information regarding the renewable groundwater quantity [14]. Groundwater is the ultimate source of water for irrigation at Brante watershed, however, there is lack of enough information on groundwater availability and rates of recharge, and also there is limited information on irrigation water use and demand together with poor documentation of irrigated area. Therefore, the objective of the study was, to evaluate shallow groundwater recharge and it's potential for dry period irrigation by integrating GIS, Remote sensing and CROPWAT model. More specifically, the study was attempted to (1) quantify major hydrologic components and estimate the recharge amount of the watershed using soil water balance and water table fluctuation method, (2) estimate the area of irrigated land in the watershed in the dry season using a satellite image taken in February 2017, (3) determine the irrigation water demand of main vegetables irrigated during the dry season using the CROPWAT model, (4) calculate the groundwater amount used for irrigation, livestock, domestic purpose, and compare with the recharge amount and other standard values.

2 Research Methodology

2.1 Description Study Area

Dangila woreda is located about 80 km south-west from Bahir Dar, along the Addis Ababa-Bahir Dar main road [15] (Fig. 1). This research was conducted in Brante watershed, which is found 10 km from the Dangla town in North West direction, in which the only transport mechanism is using three-wheel vehicles (Bajaj). Geographically, the study area extends from latitude value 11.16° N to 11.3° N and longitude of 36.77° E to 37.0° E. The climate is sub-tropical characterized by large seasonal fluctuations of air temperatures and rainfall [16]. The summer is short and cold, lasting from June through September, with maximum temperature ranging from 22.2 °C to 23.9 °C. Long-term average annual rainfall at the study area is about 1667 mm. The annual potential evapotranspiration (PET) of the study area during the study time was 1190 mm. About 93.2% of the total rainfall occurs between May and October with peaks in June, July, and August that account for 60.4% of the total annual rainfall. At the Brante watershed, crop-livestock mixed subsistence farming is the primary source of livelihood and rain-fed agriculture is predominates [17]. The majority of the land uses type is agricultural, forest, grassing land and residential. The most significant crops that grew are teff, wheat, maize, beans, and sorghum. In addition cultivation of commercial crops in the watershed such as tomato, onion, and pepper is possible during the dry season using shallow groundwater as a source. The livelihood of the community in the catchment is mainly based on mixed farming by growing crops and livestock production.

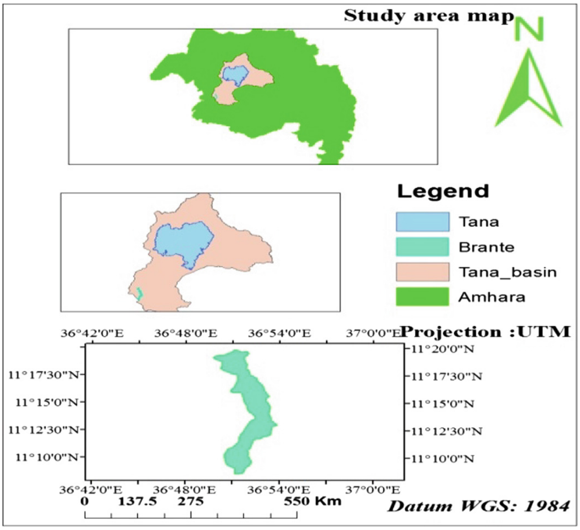

Fig. 1. (A) location of study area

2.2 Materials and Data

Hydro Meteorological Data

To evaluate the groundwater recharge and estimate the crop water requirement various quantitative and qualitative data were collected from both primary and secondary data sources. Climatological data from 1993 to 2017 was collected from Dangila meteorological station and used to estimate the crop water requirement in CROPWAT model. Additionally, climatic data, groundwater level and discharge data were collected for 2017 to estimate the groundwater recharge (see below).

Climatological Data

Missing rainfall data were filled using the arithmetic mean method and the data are checked for mean stability using T-test, variance stability using F-test. Autocorrelation test was performed for checking whether there is persistence or not, and the trend test was conducted using Spearman's rank correlation method. As it is depicted in table below, the average maximum rainfall was recorded in the month of August (387 mm) and the average minimum value obtained in the month of January (3.23 mm). The majority of rainfall in the watershed is concentrated during Ethiopian wet season (Kiremt) and the rainfall is of uni-modal in nature. The rainfall of the watershed is seasonal in which 75.52% of the total annual rainfall was covered in June to September. Climatic data from 1993–2017 is depicted in table below.

Temperatures data in the study area were taken from Dangila stations and analyzed at Microsoft Excel. The mean minimum monthly temperature was recorded in the month of January, which was 4.8 °C and the mean maximum temperature got in March that was 28.46 °C.

Available data of relative humidity were taken from Dangila meteorological station and were analyzed. The maximum and minimum values of relative humidity exist in August (83.6%), and March (45.9%) respectively and this is attributed to the rainy and dry season of Ethiopia respectively (see Table 1).

Table 1. long-term climatic and hydrological data of Brante watershed

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rf (mm)	3.2	3.5	27.0	55.0	188	273	374	387	275	112	33.3	7.8
RH (%)	51.4	47.9	45.9	47.8	62.4	77.4	83.3	83.6	80.1	75	67.1	58.8
SSH (hr/day	8.96	8.97	8.14	8.17	7.29	6.08	4.13	4.27	6.01	6	8.17	8.64
U2 (m/s)	0.77	0.88	0.99	1.05	1.07	1.00	0.95	0.92	0.80	0.67	0.60	0.65
T_{min} (°C)	4.80	6.58	8.70	10.8	12.0	12.1	12.1	11.9	11.2	10	7.38	5.10
T_{max} (°C)	26.2	27.9	28.5	28.2	26.3	23.6	21.9	22.0	23.3	23	24.85	24.9

The speed at any height can be approximately obtained from known wind speed at the known heights of observation. Danigla meteorological station workers measure wind speed in the study area and the nearby station at 2 m above the surface of the ground. The analysis indicated the minimum wind speed appeared in November (0.6 m/s) and the maximum wind speed occurred in May (1.07 m/s) (see Table 1).

Sunshine hour plays a significant role in affecting evapotranspiration. Longer sunshine hour within a day increases the evaporation rate and amount that in turn is dependent on the intensity of solar radiation. The minimum hour for the sunshine was 4.13 h per day that was recorded in July. In addition, the maximum sunshine hour was recorded in February (8.97 h/day) (see Table 1).

Ground Water Level Data

Groundwater levels were monitored in 25 hand-dug wells spread in locations within the Brante watershed. Selected farmers are responsible for recording water level in the well using deep meter once per week starting from 2014. A deep meter was used to measure the water level in the well every week since 2014. The change in water level was calculated as the difference between the level measured today and level measured at next time from the ground surface.

Stream Flow Data

The stream flow is the main output from the watershed. Gauging staff was installed at the outlet of Brante watershed to measure the depth of the flow. The stage in the river measured daily. Then the rating curve was prepared in Microsoft excel to calculate the discharge amount. Discharge is one component of the soil water balance of the catchment.

Soil, Crop and Water Use Data Collected

Soil types, common crops that are grown in the area and infiltration capacity of the soil were used for the estimation of potential evapotranspiration and crop water demand. Major crop type, irrigation method, and, date of planting other ancillary data were gathered from the farmers using pretest-structured questioners. Sixty-two farmers were used for questioners. Soil type and infiltration capacity were taken from innovation laboratory for small scale irrigation (ILSSI) project. Crop coefficient, initial soil moisture depletion, number of growing days and maximum root depth of tomato, onion, and green pepper were collected from FAO irrigation and drainage paper 56.

Water use data for irrigation, domestic and livestock were collected using water abstraction survey for 62 farmers. The data was collected from 2016 to 2017 covering one year period. The data includes the source of water for all uses, amount extracted daily for domestic and livestock, the number of households, irrigation technologies used, and vegetables type planted during dry season like tomato, onion and pepper.

2.3 Method of Analysis

Recharge Estimation

The evaluation of the groundwater resources involves several factors of which the groundwater recharge is a key [8]. An understanding of the recharge processes and the quantification of natural recharge rate are basic prerequisites for efficient and sustainable management of the groundwater resources [18, 19]. It is difficult to find a single reliable method for measuring groundwater recharge due to the complexity of the phenomenon and it is recommended to use multiple methods [20].

Quantification of groundwater recharge is a major problem in many water-resource investigations since it is a complex function of meteorological conditions, soil, vegetation, geologic material [7].

Water Balance Method: It is developed in 1948 by Thorn Thwaite and later revised by Thorn Thwaite and Mather [21]. The method is essentially a widely used, which estimates the balance between the inflow and outflow of water. According to [22], the general methodology of computing groundwater balance consists of identification of significant components, evaluating and quantifying individual components

$$R = P - ETa - Q - \triangle S \qquad [22] \tag{1}$$

Potential Evapotranspiration (PET) Estimation Using Penman Modified Method
The evaporation rate formula was modified is given by the following formula which modified by MAFF (1967, as cited in [27].

$$PET = \left(\left(\frac{\Delta}{\gamma} H_t + E_{at}\right)\right) / \left(\frac{\Delta}{\gamma + 1}\right) \tag{2}$$

Where: H_t is the available heat, Δ-is the slope of the curve of saturated vapor pressure plotted against temperature, γ: Hygrometry constant (mm Hg).

Estimation of Actual Evapotranspiration from PET
According to Bakundukize et al. (2011, as cited in [28]), the actual evapotranspiration varies with the temperature and the moisture availability during the year. In the rainy season, when the soil is at field capacity and the amount precipitation is larger than the PET, AET is maximum value

$$\text{IfP\_m} \geq \text{PET\_m, then AET\_m} = \text{PET\_m}, \tag{3}$$

$$\text{IfP\_m} < \text{PET\_m, then AET\_m} = \text{P\_m} + \Delta\text{S\_m} \qquad [29] \tag{4}$$

Change in Soil Water Storage Calculation
Recharge is estimated in the water balance model based on the accounting of soil water content. The moisture status of the soil depends on the previous day moisture content (S_(m−1)), the difference between precipitation and potential evapotranspiration and the available water capacity (AWC) of the soil [23]. According to Steenhuis and Van Der Molen (1986, as cited in [23]), soil moisture can be calculated in two scenarios.

$$\text{〚if P\_m>PET\_m,S〛\_m=〚S\_(m-1)+P〛\_m-PET\_m} \tag{5}$$

$$\text{if 〚P\_m<PET\_m,S〛\_m=Sm\_(m-1)*e\^{}(((P\_m-PET\_m)/AWC))} \tag{6}$$

Where: S_m is the soil moisture at the current time, S_(m−1) the soil moisture at previous time, P_m is precipitation, PET_m is potential evapotranspiration, AWC available water capacity of the soil.

Discharge Calculation

Rating curve was prepared from the stage reading at the outlet of the watershed. A rating curve is established by making a number of concurrent observations of the stage and discharge over a period of time covering the expected range of stages at the river gauging section [24]. If Q and h are discharge and water level, then the relationship can be analytically expressed as:

$$Q = f(h)$$

Where: f(h) is an algebraic function of the water level. A graphical stage-discharge curve helps in visualizing the relationship and to transform stages manually to discharges whereas an algebraic relationship can be advantageously used. Power type equation, which is most commonly used for rating curve preparation:

$$Q=c[\![(h+h\_w)]\!]^{b} \tag{7}$$

Where: Q = discharge (m^3/s), h = measured water level (m), h_w = water level (m) corresponding to $Q = 0$

c = coefficient derived for the relationship corresponding to the station characteristics

b = measure of the geometry of section at various depth [24] (Fig. 2).

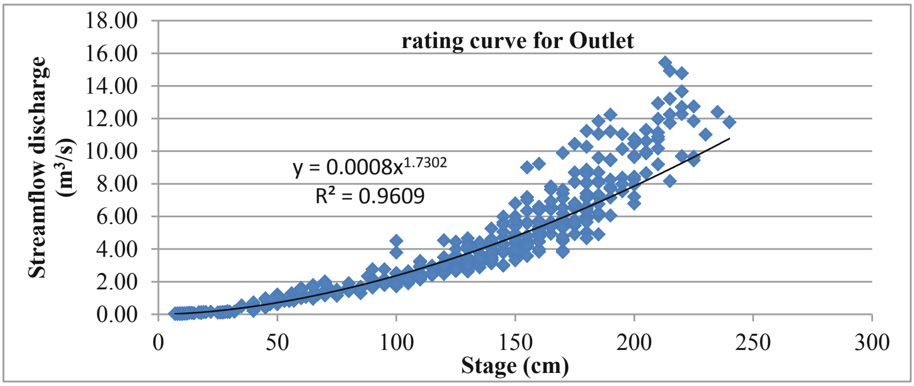

Fig. 2. Stage-discharge relationship of the Brante watershed

Recharge Calculation Using WTF Method

The water table fluctuation method (WTF) is one of the most widely used techniques for estimating groundwater recharge over a wide variety of climatic conditions [20]. The WTF method is based on the assertion that rises in water levels in unconfined aquifers are due to recharge water arriving at the water table, and that all other components of the groundwater budget including lateral flow are zero (Islam et al. 2016). The main limitations of the WTF technique are (1) the need to know the specific yield of the saturated aquifer at a suitable scale. (2) its accuracy depends on both the knowledge and representativeness of monitoring well in the catchment. (3) The method is best applied to shallow water tables that display sharp water-level rises and declines (4) the method cannot account for a steady rate of recharge [25].

$$R = S\_y * A * \Delta h/\Delta t \qquad [8] \tag{8}$$

Where S_y is the specific yield, A is the area influenced by the well and Δh is the difference in water level rise at Δt. The specific yield for the study area was used as 0.08 from Walker et al. 2016 study at Brante watershed. Average area used for groundwater storage was taken as 65% of the watershed from [30] study.

Mapping of Crop Type under Shallow Groundwater Irrigation

Remote sensing has a major advantage over ground surveying methods (theodolite and global positioning system (GPS) surveys), in that images over large areas can be analyzed in a short time and at a relatively cheaper cost. In addition, remote sensing enables the mapping of inaccessible areas [31]. To estimate the area under dry period irrigation of vegetables, data sets that were collected include a KOMPSAT-2 image, ground truth (GT) points, and farmers' surveys of water use. A very high-resolution KOMPSAT_2 image, acquired in February 2017 was used as the primary data source. Korean multi-purpose satellite (KOMPSAT-2) is a high-performance remote sensing satellite, which provides 1.0 m panchromatic image and 4.0 m multi-spectral image resolution [32].

Maximum likelihood classification algorithm was used. It is an efficient method to classify pixels of the satellite image, it is available in image analysis environment, it is unlikely to yield abnormal result [26] (Fig. 3). The confusion matrix is an established method to assess the accuracy of the classification [33].

Estimation of Crop Water Requirement Using CROPWAT Model

Crop water requirement is defined as the depth of water needed to meet the water loss through evapotranspiration (ETcrop) of a disease free crop growing in a large field under non-restricting soil conditions, including soil water and fertility, and achieving full production in a given growing environment [23]. The FAO Penman-Monteith method to estimate ETo was derived.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.43U_2)} \tag{9}$$

Where: ETo: reference evapotranspiration [mm day^{-1}], R_n: Net radiation at the crop surface [MJ m^{-2} day^{-1}], G: soil heat flux density [MJ m^{-2} day^{-1}], T: mean daily air temperature at 2 m height [°C], u_2: wind speed at 2 m height [m s^{-1}], e_s: Saturation vapor pressure [kPa], ea: Actual vapor pressure [kPa], e_s-e_a: Saturation vapour pressure deficit [kPa], Δ: Slope vapor pressure curve [kPa $°C^{-1}$] γ: psychrometric constant [kPa $°C^{-1}$].

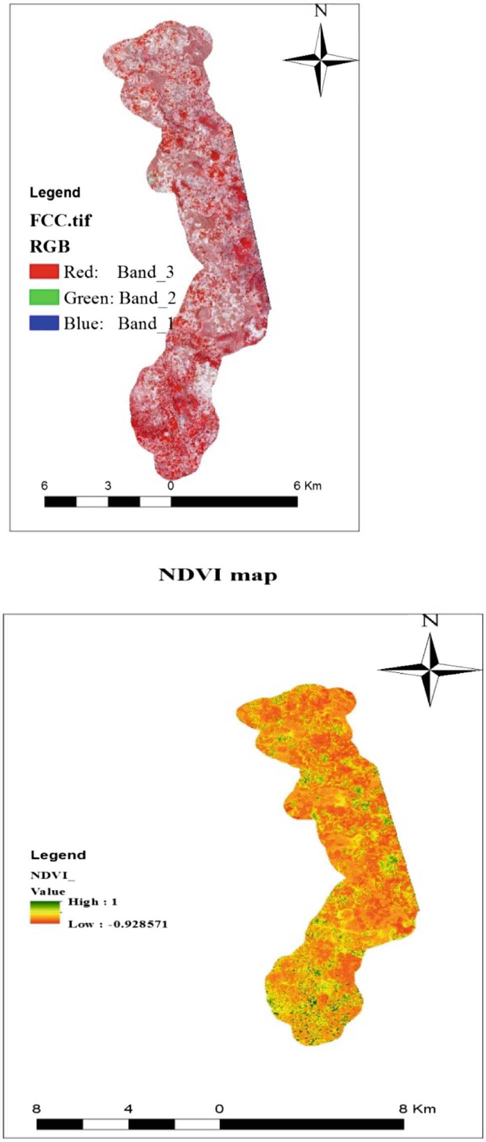

Fig. 3. Image enhancement (A) false color composite (B) NDVI

It was assumed that for each month, if the total quantity of water available, given by the sum of monthly rainfall and water stored in the root zone was sufficient to satisfy the monthly crop water need, no irrigation is needed. Otherwise, if the rainfall is insufficient and soil water storage is depleted, the difference is the deficit that should be supplied by irrigation. Irrigation water requirement is calculated as

$$IWR = \sum\nolimits_{i=1}^{n} (ET_o * K_c - P_{eff}) \quad (10)$$

Where: IWR = irrigation requirement, A = irrigate area, 〖ET〗 _o = reference evapotranspiration, = K_c crop coefficient, P_eff = effective precipitation.

Groundwater Use Calculation

The total amount of withdrawal groundwater in the study area throughout the catchment consists of irrigation, domestic and livestock water uses. Apart from the evaluation of the groundwater potential, this study also attempted to quantify the groundwater use. This objective was fulfilled by collecting data using questioners. Calculations for livestock water consumption were using the following equation [34]. By assuming livestock water consumption from Brante river is negligible.

$$\mathrm{NA} * \mathrm{CR\ per\ animals} = \mathrm{average\ daily\ use}\left(\mathrm{m}^3/\mathrm{day}\right) \quad (11)$$

Where: NA was a number of animals, CR was consumption rate

During the rainy season, agriculture was supported by precipitation and surface water, but once the rain had stopped, gardens needed watering. The daily volume of water applied for irrigation of major vegetable was calculated from farmer response on the number of buckets used and calibration amount the bucket holds. Irrigation water use calculated as,

$$\mathrm{IA}\left(\mathrm{m}^2\right) * \mathrm{Daily\ water\ applied\ (m)} * \mathrm{growth\ season\ (days)} = \mathrm{IWR}\left(\mathrm{m}^3/\mathrm{season}\right) \quad (12)$$

Where IA is irrigated crop area, IWR is irrigation water requirement.

Calculation for domestic use: Shallow hand dug well, bored hole and springs provide access for drinking water for Brante watershed. However, most of the domestic water demand is supplied from shallow hand dug well. Water demand for human consumption was estimated by the following formula [29].

$$\mathrm{AED\ (mm/year)} = (\mathrm{DC}\left(\mathrm{m}^3/(\mathrm{day.Well})\right) * \mathrm{number\ of\ well} * 365\ \mathrm{days/year} * 1000\ \mathrm{mm/m})/\mathrm{Area}\left(\mathrm{m}^2\right) \quad (13)$$

Where AED is annual equivalent depth, DC is daily consumption.

3 Result and Discussion

3.1 Groundwater Recharge Estimation

Rainfall and Potential Evapotranspiration

Rainfall is the principal means for replenishment of moisture in the soil water system and it was the only input to the moisture water balance. Since the irrigated area was small and farmer use bucket to irrigate, percolation due to dry season irrigation was assumed to be negligible. Rainfall was the main hydrological parameter for water balance approaches to estimate the recharge in the study area. In the Brante watershed, Dangila meteorological station rainfall data is recording daily and this data was used for this study. From the analysis, the annual rainfall amount during 2017 was 2000 mm or 113575000 m^3 (Fig. 4).

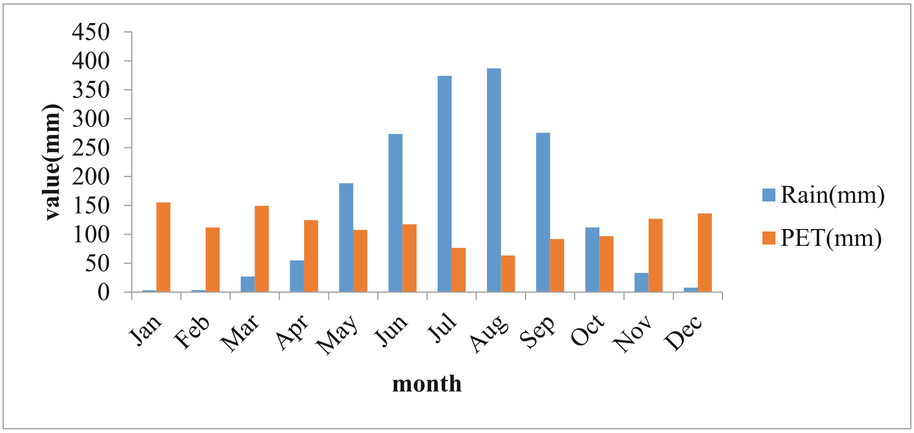

Fig. 4. Monthly rainfall and potential evapotranspiration of the watershed in 2017

Table 2. Monthly potential evapotranspiration value

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T	27	28	29.3	28.2	24.9	24.5	22.6	22	23	24.5	25.4	26.6
e_s	16.5	17.4	19.0	19.4	17.4	17.2	15.9	15.4	16	16.7	16.2	15.8
RH	0.4	0.6	0.4	0.6	0.7	0.8	0.8	0.8	0.8	0.8	0.6	0.5
e_a	6.8	9.5	8.4	11.1	12.3	13.0	12.7	12.8	12	12.6	10.1	8.1
N	9.9	7.2	7.8	6.7	6.0	6.9	4.6	3.9	5.4	5.8	8.5	9.3
N	11.4	11.6	11.9	12.3	12.5	12.7	12.6	12.4	12	11.7	11.5	11.3
n/N	0.87	0.62	0.65	0.55	0.48	0.54	0.36	0.31	0.5	0.50	0.74	0.82
Fa (n/N)	0.70	0.54	0.57	0.50	0.46	0.50	0.39	0.35	0.4	0.47	0.62	0.67
H_t	4.26	3.90	4.51	4.31	3.96	4.24	3.29	3.04	3.7	3.55	3.99	3.91
Eat	1.15	1.2	1.72	1.17	0.7	0.8	0.63	0.42	0.6	0.5	0.72	0.68
Δ/γ	4.1	4.0	4.4	4.1	3.6	3.6	3.2	3.1	3.4	3.5	3.7	3.8
PET(mm/month	149.9	116	168	128	91	87	62	49	71	73	102	101

In 2017, maximum rainfall was recorded in August, which was 376 mm, and from the graph, it is clear that there was no rainfall during November, December, and January which is corresponding to Ethiopia dry season (Table 2).

The annual potential evapotranspiration of the watershed was calculated as 1190 mm. The maximum potential evapotranspiration i.e. 168.5 mm was obtained in March, which was the dry season and also it is related to the highest ambient temperatures (29.3 °C) of the area. However, relative humidity was minimum when the potential evapotranspiration was high.

Actual Evapotranspiration Estimation by Soil Water Balance Method

The average actual evapotranspiration in the study area was calculated as 698 mm or 39637675 m^3. The graph below highlights surplus soil moisture was existed when the rainfall amount was higher than potential evapotranspiration and these phenomena were appeared in Ethiopian wet season only. Consequently in dry season, for replacing soil moisture deficit in the soil profiles and for better crop production, irrigation has no substitute (Fig. 5).

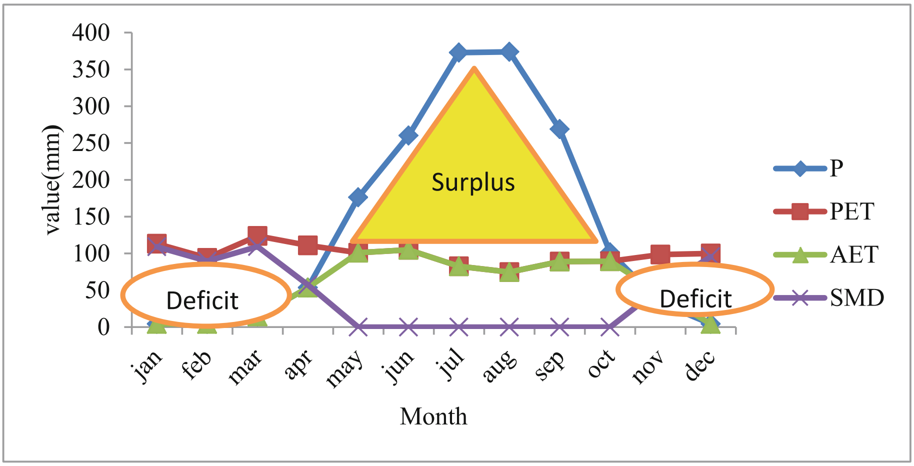

Fig. 5. Graphs shows the annual soil water balance of Brante watershed

Stream Discharge Calculation: From the prepared rating curve, the estimated streamflow during 2017 was 970 mm or 55083875 m^3 per year, which accounts for 48% annual rainfall. Contrary to the findings of Bizimana et al. 2016 on the surface runoff potential, which was 500 mm (46% rainfall) the current result seems higher (Fig. 6).

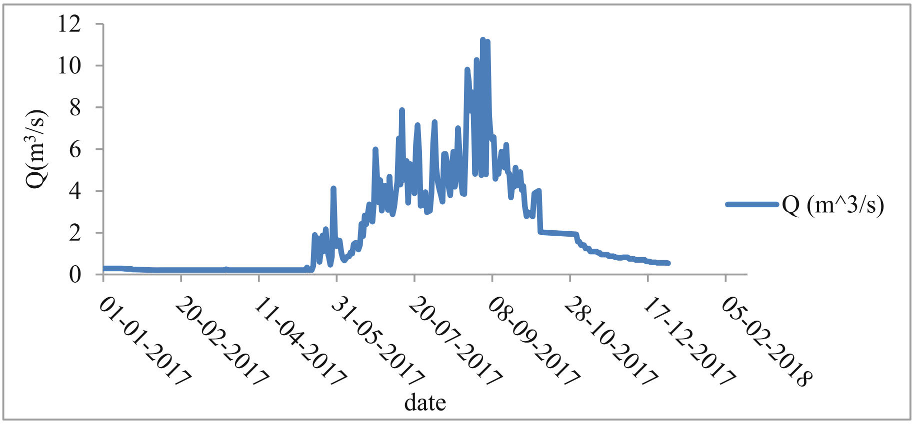

Fig. 6. Stream flow hydrograph of Brante watershed in 2017

As the above hydrograph shows, the discharge rate was increased from May to the end of August and it tends to decline at September and follows the same pattern up to

December that is associated with amount of rain fall. In August 2017, maximum rainfall was recorded compared to the other months that were 376 mm. This result indicates the excess amount of water almost half of the rainfall was taken out from the watershed through the stream flow.

Daily soil moisture calculations were made from 1st of January to December 30th 2017 using initial soil moisture of 8.5 mm. The available water holding capacity of the area was calculated as 70 mm, 120 mm and 140 mm for different soil type and root depth. The change in storage was calculated as the difference in available water at final and at initial time. The annual change in soil moisture storage was calculated as 20 mm or 1135755 m^3 (Table 3).

Table 3. Soil water balance components by assuming during recharge (wet season) there is no significant abstraction

Parameters	Water depth (mm)	Volume (m^3)
Rainfall	2000	113,575,000
Actual evapotranspiration	698	39,637,675
Discharge	970	55,083,875
Change in soil moisture storage	20	1,135,755
Ground water recharge	312	17,717,690

From water balance equation, recharge was 17717690 m^3 or 312 mm. Even though this result is below the previously reported 504 mm recharge using SWAT as simulator by Binziman et al. (2016), it suggests that there is a significant amount of recharge. A difference between values could be attributable to the difference in the method used, variation of rainfall, and uncertainty in determination of parameter.

Recharge Calculation Using WTF Method: Based on Walker et al. (2016, as cited in Walker et al. 2018), specific yield could be taken as 0.08; the area used for ground water recharge was 0.65 * 56787500 m^2, which yields 36911875 m^2. The water levels fluctuations in the monitoring wells showed that the water levels rose and fell according to rainfall events and withdrawal until the end of the rainy season wherein the absence of input of water, the water level continuously fell.

The water level in the well was measured from the ground surface. In Fig. 7, a slight rise of ground water in well number eight start in June and continue to rise up to August. However, when there is no rain, the depth to water was dropped 10 m below the ground. The amount of water reach ground water table during the wet season was calculated as the sum of June, July and August i.e. 15384870 m^3, or 416 mm.

Limitations of the Approach

Because of the lack of meteorological station distributed over the water, the spatial distribution of the recharge over the study area not investigated. Another limitation in

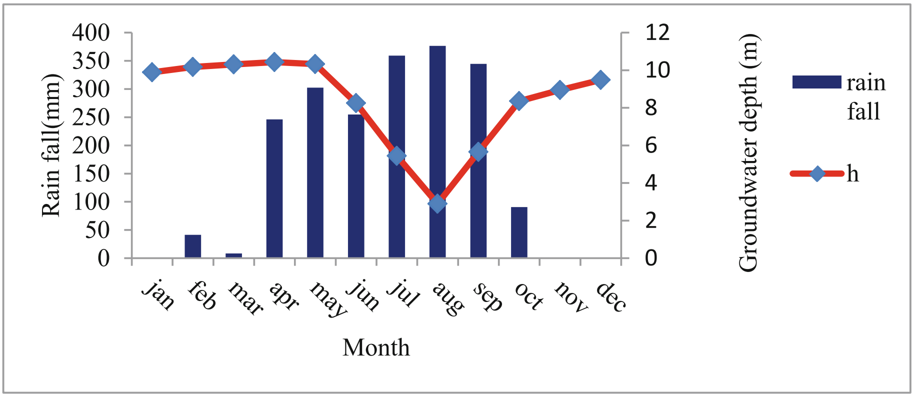

Fig. 7. Well Hydrograph for well number 8, in 2017

the methodology involves the issue of using multiple recharge estimation mechanisms since the result was based on only water balance approach and WTF method. Although the water balance approach widely accepted, it suffers from some limitations due to consider locally renewable groundwater availability as the major controlling parameter for groundwater irrigation potential. In addition, it assumes non-limiting conditions in terms of other fundamental physical properties, e.g. soil and water quality, terrain slope, and groundwater accessibility for the implementation of groundwater irrigation. In addition, there was short period of data in water level monitoring and stage measurement that prohibit to do long term ground water recharge analysis. The assumption for WTF may not always valid.

3.2 Mapping Groundwater Irrigated Crop and Area Estimation

The irrigated vegetables during dry season were mapped in Arc map environment from satellite image using supervised maximum likelihood classification and accordingly their area was estimated and displayed below.

Figure 8 depicted most of the area in the watershed below the main road which have ground truth data was covered by bare land and grazing land during February 2017. Irrigated vegetables (onion, tomato, green pepper) cover 4 hectare i.e. only 0.18% of the watershed area. Overall land use classification accuracy was 79% (Table 4).

3.3 CROPWAT Model Result

Reference Evapotranspiration Calculation

The lowest ET_o was obtained in July and it was about 2.97 mm/day or 90.2 mm per month; while the highest ET_o occurs during April and was about 4.56 mm/day or 136.8 mm/month. The average ET_o of the area was calculated as 3.62 mm/day or 109.9 mm/month.

Effective Rainfall: From the CROPWAT result, effective rainfall was obtained as 52% of the rainfall i.e. 1036 mm per annum out of the total average annual rainfall 2000 mm,

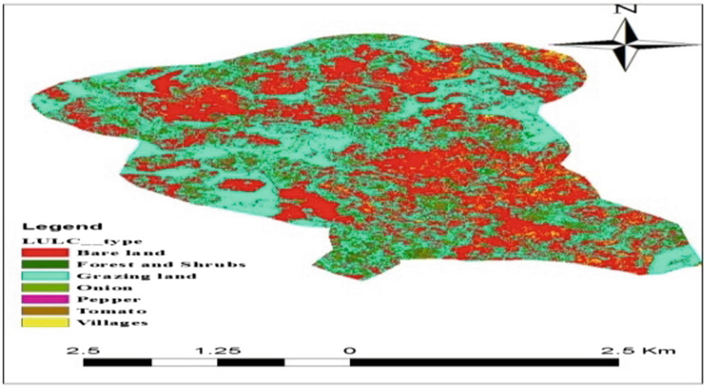

Fig. 8. Land use land cover map of Brante watershed below main road

Table 4. Area coverage of each land use type in the watershed below the main road

Land use type	Area (ha)	Percentage
Grazing land	803.6	34.35
Bare land	1150.4	49.23
Residential	135.7	5.80
Onion	1.59	0.067
Tomato	1.09	0.046
Pepper	1.34	0.057
Forest and Shrubs	245.2	10.48

and the losses estimated as 48% of rainfalls in the study area. The minimum amount of effective precipitation was found in January that is 3.3 mm. during the dry period effective rain fall was almost equal to the rain fall the water shed received due to the reason that the rain fall is too small and could not generate significant amount of loses. Comparison of the mean monthly rainfall and evapotranspiration indicates that, for the maximum crop production in the area during the dry season, irrigation is the most important choice (Table 5).

3.4 Calculation of Irrigation Water Applied

The water use questioner was conducted below the main road that divides the watershed in to two. So that groundwater use for irrigation was calculated for the watershed that found below the main road. From Table 6, it was observed that during irrigation season excess depth of water was applied for tomato, onion, and green pepper than the demand estimated by CROPWAT model.

Table 5. Irrigation water requirement (mm/month)

Month	Onion	Tomato	Pepper
Jan	17.1	25.7	4.5
Feb	87.4	67	64.5
Mar	116.7	103.5	91.9
Apr	103.4	105.1	91.9
May	8.6	12.6	8.4

Table 6. Actual quantities of water applied by farmer and CROPWAT result

Crops	Area (m^2	Applied (mm/day)	Growing per (dy)	Applied water (mm/seas)	Applied (M^3/season)	IWR (mm/season) (CROPWAT)	M^3/Season (CROPWAT)
Tomato	10948	2.5	145	377	4112	314	3425.7
Onion	15920	2.7	150	400	6384	333	5269.5
Pepper	13408	2.5	120	312	4183.3	261	3499.5

Calculation of Water Used for Livestock

The total volume of water used by livestock was 196.2 m^3 per day. Even though Brante river is perennial, From the questioners, the information was that the farmer use hand dug well for livestock for months starting from November to May, which counts 211 days. So that the total water demand for livestock per the operating season is 41603 m^3. This result now provides evidence to manage groundwater for animal watering.

Calculation of Water Used for Domestic Use

The total number of functional hand-dug well and borehole is 925. The average daily domestic consumption per well in a single day was calculated as 160 L (0.16 m^3), for eight households which is equivalent to 20 L per capita per day. The annual equivalent depth for domestic consumption represents approximately 1.7 mm per year or 62750.19 m^3 per year. Generally, Seasonal change in water use was due to the changing availability of groundwater in wells, surface water, and the frequency of rain events. The water use is the highest during the autumn season due to high availability and increased demand for water by agriculture.

Comparing Groundwater Use and Recharge

It was necessary to determine whether shallow groundwater recharge could support for all ground water uses. The groundwater use for irrigation, livestock and domestic was calculated as 164503 m^3, which were (60150 m^3 + 41603 m^3 + 62750.19 m^3). The annual recharge in the watershed was 17717690 m^3. Therefore, the groundwater use in the study area was 1% of the annual recharge. Barring other influencing factors, the quantities of groundwater available in study areas are capable of sustaining groundwater-irrigated vegetable production for now and in the near future without affecting long-term groundwater storage (Table 7).

Table 7. Computation of the stage of ground use for irrigation during 2017

No	Description	Values
1	Annual rainfall in the watershed	113,745362.5 m^3
2	Annual recharge from rainfall	17,717690 m^3
3	Percentage of recharge to rainfall (2/1) * 100	15.9%
4	Domestic water use for the watershed during the whole year	62,750 m^3
5	Livestock water use for the dry season	41,603 m^3
6	Irrigation water use for the dry season	60,150 m^3
7	Total groundwater draft during the year (4 + 5 + 6)	164,503 m^3
8	Percentage of groundwater draft to recharge (7/2) * 100	1%
9	Utilizable water for irrigation (2 − (4 + 5)	1,636421 m^3
10	Level of groundwater development for irrigation (6/9) * 100	4%
11	Stage of groundwater development	Underexploited

From this evaluation, it could be stated that the water withdrawals within the watershed are very unlikely to deplete the groundwater aquifers in the Brante watershed. Considerable opportunities, therefore, exist for improving the population's livelihood through the development of the watershed water resources if the estimations elsewhere are considered reliable.

Meanwhile, if for any reason (e.g., underestimation of the daily withdrawal volumes reported by the surveyors, or even inconsistent assumptions in the withdrawal estimation, an estimation error of 100% of the withdrawal volume is considered, a correction will merely bring it to 329,006 m^3, which is still remarkably low compared to the 17,717690 m^3 of recharge.

Comparing the recharge volumes and the crop water requirement for the main vegetable grown in both study areas, there exist the potential to increase groundwater-irrigated land up to 1000 ha.

Accuracy Assessment of Water Use

Individual variations of water use were noticed during the water use interviews. However, for simplicity, these changes in water use were omitted from the results because they were observed as an inconsistent or insignificant addition to the total village water use. occasionally less water was used from ground water for domestic use during the wet season seasons the farmer washes their clothes using river water and by collecting rain in the pot. Seasonal production of products such as coffee required a couple of buckets of water at each production session. More buckets were extracted occasionally when there were weddings and other ceremonies.

Benefits and Constraints of Groundwater Irrigation in the Study Area
They use the river and shallow well as a water source for their livestock watering purpose. Groundwater from shallow well is the main for irrigated production of vegetables and fruit during the dry period. Moreover, the ease of access to shallow groundwater sources and the erratic variability of rainfall distribution of the area made the communities depend highly on it. Most of the irrigators use hand-dug wells and dugouts produce vegetables on plot sizes between 0.01 and 0.025 ha.

The area cultivated varies from one year to another, and is influenced by the profitability of the previous season, access to credit facilities, availability of land, and the rainfall situation of the preceding season are among other factors. Most of the landowners engage solely in rain-fed agriculture and do not cultivate in the dry season.

Mostly buckets and cans are used for watering of crops, though a few of the irrigators have invested in small-capacity motorized pumps. In addition, 54.5% of irrigation users take credit for accessing technologies for water lifting and delivering to site. 48.9% of groundwater used for irrigation is at January, February, March, and April; 81% of irrigators use shallow hand dug wells. Many of the irrigators in the study areas mentioned that groundwater-irrigated vegetable production is profitable and an important source of income to the household. However, they do take losses in years of poor rainfall or low recharge, which results in less water being available in the shallow aquifers. Despite this study did not include in-depth data collection and analysis to determine the level of revenue irrigators get from groundwater irrigation, an attempt was made at quantifying the profits through an extensive informal discussion with an irrigator at the watershed who is a well-known landowner and cultivated about 0.02 ha of onion and pepper.

The net revenue, based on the 2017 irrigation season, was 3000 birr, which is equivalent to united state dollar 115, based on the June 2017 exchange rate. Most of the irrigators are full-time farmers in the rainy season, but some of them are employing in animal rearing and therefore profits from groundwater irrigation are considering additional income. Notwithstanding that groundwater, irrigation was profitable, it was constrained by many challenges; including lack of access to credit facilities, seed access limitations, lack of appropriate drilling technology, market access, and extension services.

Moreover, the farmer willingness to use groundwater for irrigation is weak. This is due to the reason that it takes a long time to transport water from hand dug well to irrigation site manually that is tedious and labor intensive. One of the farmers has three shallow groundwater well but still, he did not use for irrigation purpose. The reason was that rather than searching for, he waits someone to give him seed, and advice to use irrigation.

4 Conclusions

The annual recharge to the groundwater aquifers in the study area was estimated to be 312 mm (15.7% of the mean annual rainfall). This allows concluding that a simple water balance formula could be used to quantify the point recharge due to rainfall. The image classification result indicates that bare land was the dominant type of land use followed by grazing land during February 2017. The perennial crops such as forest, bare land, grazing land were classified with reasonable accuracy, while seasonal irrigated vegetation is poorly distinguished on the image.

The CROPWAT model analysis leads to conclude crops require more amount of water at their development or flowering stage. From the abstraction survey analysis, it is possible to conclude that most of the farmer applied more water for irrigated vegetables. The communities abstract 41603 m^3 of water from the hand dug well for livestock, 60150 m^3 of water abstract by the farmer to irrigate vegetables at the dry season, and 62750 m^3 of water for domestic. In conclusion, the actual water withdrawals from the Brante aquifers for all uses were relatively low compared to the annual recharge. Estimated groundwater use was 1% of the annual recharge to the watershed. These low withdrawals mean possibilities for further groundwater irrigation expansion.

5 Recommendations

Future work should be performed to determine if the water balance method outlined in this research, or a close variation of this method, could be used to accurately estimate monthly available water potential. If funding is not readily available to communities' for the construction of pumping wells, water containment projects might be the only option.

Although the results of this study can be considered substantial for preliminary steps in the watershed ground water resources management, additional studies need to be carried out for their validation and for the planning of sustainable water management.

The following are recommended

- Successful identification of agricultural crop could have required multi-temporal image at least at the middle and late growth stage. Combining images of a very high resolution with images of a medium resolution (e.g., LandSat-TM) could be the way forward to assess the existing as well the potential of shallow groundwater irrigation in Brante watershed.
- For most agricultural crops, especially short season crops and areas with multiple crops grown per season, it is suggested that mapping should be done closely as possible as acquisition time of the image
- Groundwater abstraction for irrigation should increase by expanding irrigation area.
- The amount of water applied for the crop by the farmer should be in accordance with the demand for better production.
- Encouraging the use of common dug wells or community irrigation wells, and maintain an equitable and fair distribution of water between the users particularly in areas where elders are lives and unable to dig wells.
- Soil and water conservation has to be implemented to reduce runoff as much as possible. In addition, sometimes the obtained information of farmer during fieldwork has not enough reliability. Consulting with local agriculture agent is suggested.
- Satellite image for irrigated area identification and classification should use for irrigation which have large area.

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