ISSN 2316-6886
WRIM

Water Resources and Irrigation Management
v.11, n.1-3, p.47-65, 2022
DOI: 10.19149/wrim.v11i1-3.2909

Cruz das Almas, BA, Brazil – https://www3.ufrb.edu.br/seer/index.php/wrim/index

ORIGINAL PAPER

Assessment of irrigation water potential and water requirements of selected crops in the Wabe-Shebelle River Basin, Ethiopia

Tasisa Temesgen[1*]; Girma Mideksa[2] & Teshome Seyoum[2]

[1]School of Natural Resources Management and Environmental Sciences, Haramaya University, Ethiopia
[2]Departement of Irrigation Engineering, Haramaya University, Ethiopia

Abstract: Knowing water resources for irrigation available and water requirements of selected crop are important for planning irrigation. From a number of uncertainties, the watershed constrained that stream flows in the watershed have not been identified and matched with the water requirements of some crops commonly grown in the watershed. So, the study was initiated with the objective of evaluating irrigation water potential and water requirements of selected crops under the Wabe Shebelle River Basin conditions, Ethiopia. Estimation of irrigation water requirement and surface water resources of river catchments were the steps followed to assess the irrigation potential of the study area. In these identified irrigable areas, three crops such as maize, sorghum and potato were selected and their gross irrigation demands were calculated using nearby meteorology stations. The discharges at un-gauged sites were estimated from gauged sites by applying runoff coefficient method and results were obtained on a monthly basis. The irrigation requirements of the identified command area vary according to nearby meteorology stations and type of crops selected. By comparing gross irrigation demand of irrigable land with available flow in rivers, a gross irrigation demand of potentially irrigable land of 58,995.15 ha are not fulfill with the present flow. It was concluded that, the total annual irrigation water potential/annual available flow above abstraction site is 335.7 m^3 s^{-1} or 2.9 hm^3.

Keywords: GIS, water resources, irrigation water availability, irrigation requirements.

Introduction

With declining productivity in rain-fed agriculture and with the need to double food production over the next two decades, water has been recognized as the most important factor for the transformation of low productive rain-fed agriculture into most effective and efficient irrigated agriculture (FAO, 2014; Alsayim et al., 2022; Neway and Zegeye, 2022). It is obvious that the utilization of water resources in irrigated agriculture provide supplementary and full season irrigation to overcome the effects of rainfall variability and unreliability. Hence,

[*] Corresponding author: E-mail: tasisatemesgen@gmail.com
Editors: Mairton Gomes da Silva & Petterson Costa Conceição Silva
Received in: March 29, 2022
Accepted in: June 22, 2022

the solution for food insecurity could be provided by irrigation development that can lead to security by reducing variation in harvest, as well as an intensification of cropping by producing more than one crop per year (Awulachew and Ayana, 2011; Makhlof et al., 2021).

The volume of water obtainable for irrigation will depend on the outcome of hydrological studies of surface water (FAO, 2014). The amount of runoff in river catchments with limited stream flow data can be determined from runoff coefficient of gauged river basin (Babar and Ramesh, 2015). After the amount of river discharges both gauged and un-gauged are quantified, an important part of the evaluation is the matching of water supplies and water demand. Irrigation contributes to rapid transformation of agriculture as present-day agriculture is dominated by rainfed single crops.

The current irrigation development in Ethiopia is about 0.7 Mha, and the performance of the existing schemes is not well understood. As different result shows that 86.5% of schemes are operating, 74.1% of command area is under cultivation and only 46.8% of the planned beneficiaries have benefited from implemented irrigation. For evaluating performances of large-scale schemes in watershed, we used irrigation water delivery performance and output performance indicators applied to six large-scale schemes. Scheme level performance indicators results showed that all of the schemes considered have supplied adequate to excess amounts of water during the period. In some advanced scheme that uses pump diversion showed higher water use efficiency than other schemes that are using simple gravity diversion types. In this case it might be the running costs of pumps that have encouraged efficient management of water (Awulachew and Ayana, 2011).

The main objective of this study was to assess the irrigation water potential and crop water requirements in the basin for future planning and development possibilities in Ethiopia.

Material and Methods

The materials and data used to assess the irrigation water potential and to evaluate crop water requirement of selected crop for potentially suitably surface irrigation of this study were GPS, satellite images, topographic maps, soil data, DEM (Digital Elevation Model), software's such as CROPWAT 8.0, ArcGIS10.1, ArcSWAT10.1, and ENVI 4.5. Streamflow data/discharges of two gauging stations such as Dawe and Hamaresa rivers both on upper part of Gobele river were obtained from the Hydrology Department of the Ministry of Water, Irrigation and Energy. The streamflow data were used to assess both water resources potential of the gauged and un-gauged sites for irrigation purpose.

Meteorological data

Meteorological data of Haramaya, Kersa, Harar, Kulubi, Hakim Gara, and Girawa of 30-year stations were collected from NMA and grid interpolated rainfall data of Kulubi and Haramaya stations were obtained from ILRI GIS database. These data were used to estimate irrigation water requirements of some selected crops using CROPWAT8.0. In addition, the rainfall data were used to calculate average area rainfall using the Thiessen polygon extension in ArcGIS. The area rainfall was used in the estimation of stream flow at un-gauged sites from gauged sites.

Data pre-processing and checking

Before using the collected data for this study, the hydrological and meteorological data were checked and errors were removed. The analysis was extended to hydrological and meteorological data to prepare input data for water resources assessment and irrigation water requirement estimation.

Filling missing rainfall data

Missing records of the rainfall data were estimated by using normal annual precipitation method where annual rainfall variation of different stations within 10% of the normal annual precipitation at station X, then a simple arithmetic average procedure has to be used to estimate missed precipitation and normal ratio method which was recommended to estimate missing data in regions where annual rainfall among stations differ by more than 10% (Dingman, 2002). This approach enables estimation of missing rainfall data by weighting the observation at m gauges by their respective annual average rainfall values (Gebreegziaber, 2004).

Consistency of stream flow and rainfall data

To prepare the streamflow and rainfall data for a further application, the consistency was checked using double mass curve analysis. A double mass curve is a plot of cumulative values of one variable against the accumulation of another quantity during the same time period (Albert, 2004). A break in slope indicates a change in the constant of proportionality (Albert, 2004; Dai, 2016). If the streamflow and rainfall data are inconsistent, it can be adjusted by proportioning, using correlation coefficient, between the stations (Toth, 2013; Addor and Melsen, 2019).

Computing irrigation water requirements

In order to estimate irrigation water requirements of some selected crops in the potential irrigable sites, the definition of area of influence of the meteorology stations s using Arc GIS inside and around the watershed was assessed. To obtain a spatial coverage of climate data over the study area, each station was assigned to an area of influence using the Thiessen polygons method (Gurara et al., 2021). This method assigns an area of 'nearest vicinity' to each climate station as presented in Figure 1.

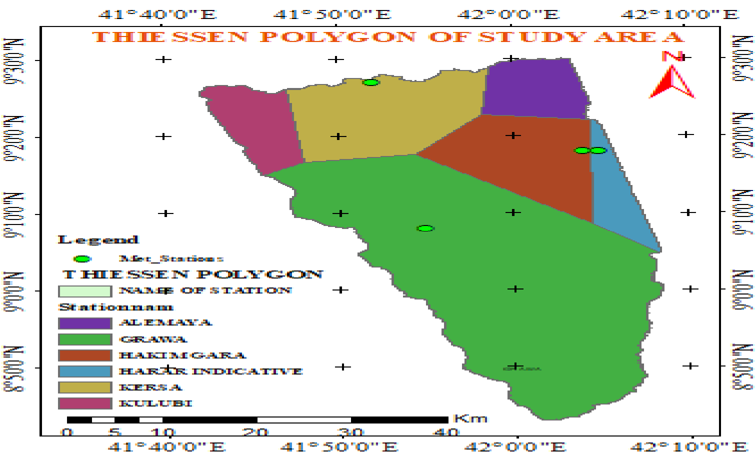

Figure 1: Thiessen polygons showing an area of influence of meteorology stations s in the study area.

The data of the meteorology stations of Girawa, Hakim gara, Harar Indicative, Haramaya, Kersa, and Kulubi were taken to calculate irrigation water requirement of the identified irrigable area. Therefore, recorded data of the Girawa station identified to use for this study from the FAOCLIM has taken for creation of the database. Then based on the cropping pattern of the study area, obtained from East Hararge agricultural office, three crops such as potato, sorghum and maize, were selected to estimate the water demand on a monthly basis. Planting dates for potato, Sorghum and maize were chosen in such a way that the planting dates coincided with the local cropping calendar at the nearby meteorological stations. Reference evapotranspiration (ETo) and other climatic data were derived from the computation for crop water requirement estimation. The respective crop coefficients for the crops were selected based on FAO (2014).

Then, gross irrigation water requirements of the crops at the identified potential irrigable sites were estimated by considering distribution efficiency – Ed (Ed = Ec × Eb; where: Ec – supply conveyance efficiency and Eb – field canal efficiency) of 65%, application efficiency of 65% for surface irrigation and assuming 75% of water conveyance efficiency from the source to identified command area as follows:

$$ETc = ETo \times Kc \quad (1)$$

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

Where:
ETc – crop evapotranspiration (mm day^{-1}); ETo – reference crop evapotranspiration (mm day^{-1}); Kc – crop coefficient (dimensionless, a function of plant type, growing period, relative humidity and wind); IWR – irrigation water requirement (mm) and Peff – effect rainfall (mm).

Effective rainfall (Peff) was calculated on monthly basis by the expression given by dependable rain (FAO/AGLW formula) method as follows: Peff = 0.6*P-10/3 for Pmonth ≤ 70/3 mm and Peff = 0.8*P-24/3 for Pmonth > 70/3 mm (FAO, 1986).

Gross irrigation water requirement (GIWR, m^3 month^{-1}) was calculated by:

$$GIWR = \frac{IWR}{Ea} \times 100 = \frac{NIWR}{Ea \times Ec} = \frac{FWS \times A_{crop}}{E} \quad (3)$$

Where: IWR – irrigation water requirement (mm); NIWR – net irrigation water requirement (mm); E = water conveyance efficiency; FWS – field water supply (L s^{-1} ha^{-1}); A_{crop} – potential irrigable area to be cultivated with a selected crop (ha); Ea – field application efficiency in percent.

Estimating surface water resources potential of river catchments

The available surface water of the catchments was estimated using stream flow discharges of the gauging stations (obtained from the Ministry of Water, Irrigation and Electricity) and rainfall data (obtained from NMA and ILRI GIS database). The stream flows that were used as input to determine discharges at ungauged sites were measured at the gauging stations inside the study area (Table 1). The rainfall data should be converted to dependable rainfall (FAO, 2002).

Table 1: Hydrometric stations inside the study area

No	River	Site	Start date	End date	Lat	Lon	DA (km^2)
1	Hamaressa	Near Harar	1988	1997	9º19’48”	43º4’48”	63.71
2	Dawe	Near gara	1999	2008	9º19’48”	41º48’0”	150.4

Lon – latitude; Lon – longitude; DA – drainage area.

Estimating discharges at un-gauged sites from gauged sites

The rainfall data analysis results and discharges from gauged sites were used to estimate the streamflow at the ungauged sites in the study area. Since irrigation potential of perennial rivers was considered in this study, a long-term average of stream-flow at gauged sites and mean monthly areal rainfall of the sites were used to estimate the discharges at ungauged sites. This is performed by transferring the runoff coefficient of the gauged sites to ungauged sites (Goldsmith, 2000). According to Goldsmith (2000), to estimate mean monthly runoff volume of un-gauged sites from gauged sites, catchment characteristics such as land cover, soil type, and catchment slope ranges should be similar, and distances between the gauged and un-gauged river catchments should not be more than 50 km and minimum 10 years mean monthly river flow at the gauged sites should be available. Based on these criteria, the gauged and un-gauged river catchments soil, slope, and land cover maps were derived using FAO (1997) digital soil map of East Africa, DEM, and SPOT5.4.3 satellite image, respectively. Then runoff volume per month at the ungauged site was estimated using the following steps:

1. Both gauged and un-gauged catchment areas were calculated.
2. Point rainfall data of stations both in and around gauged and un-gauged catchments were converted to area or average rainfall over an area of river catchments using Theissen polygon method in ArcGIS.
3. Both un-gauged and gauged river catchments in terms of their land cover/use, soil type and slope range were compared to determine their similarities.
4. Runoff coefficient from the ratio of mean monthly discharge to mean monthly areal rainfall of gauged catchments were determined.
5. Above steps were followed to estimate monthly average runoff of the un-gauged river catchments from gauged river catchments using the following equation (Yarahmadi, 2003).

$$\text{Q ungauged} = \left(\frac{\text{A ungauged}}{\text{A gauged}}\right) \times \text{Q gauged} \quad (4)$$

A physical similarity measures

According to Li et al. (2015) the physical similarity was defined based on comparison of such catchment descriptors as catchment topography (mean slope, Parajka et al., 2005), land cover (forest, cultivated land, grass, shrubs, settlement, built-up area and bush, Oudin et al., 2008), and soil type (Cambisols, Luvisols, Fluvisols, Vertisols and Leptosols,). These characteristics are generally considered as the major drivers of the physical processes of the catchment. The physical similarity among catchments was measured by means of a weighted Euclidean distance:

$$S = 1 - Dist_{a,b} = 1 - \sqrt{\sum_{j=1}^{j} w_j\left(X_{a,j} - X_{b,j}\right)^2} \quad (5)$$

Where: S – is the similarity index of catchment *a* to catchment *b*; $Dist_{a,b}$ – is the Euclidean distance between catchment *a* and *b*; *j* – indicates one of a total of *J* catchment descriptors; $X_{a,j}$ and $X_{b,j}$ – are the standardized values of that catchment descriptor at the ath catchment and bth catchment, respectively; w_j – is the weight attributed to the jth catchment descriptor. The application of equation involves measures generally having different units and scales, and therefore requires a standardization of the descriptors. The standardization was carried out by dividing each descriptor by the maximum of the descriptor: $X_{k,j}/max\ (x_{k,j})$. Where: *k,j* – is the value of the catchment descriptor at the kth catchment before standardization. Weights were given by:

$$w_j = \frac{\Delta X_j^2}{\sum_{j=1,J} \Delta X_j^2}, \text{ of which } \Delta X_j = \frac{\sum_{k=1}^{[m/2]} X_{k,j} - \sum_{[k=m+3/2]}^{m} X_{k,j}}{[m/2]} \quad (6)$$

Where: ΔX_j – is the difference among the jth descriptor of the catchments; $X_{k,j}$ – is arranged in a descending order; *m* – is the number of catchments.

Transferring discharges of gauged rivers to the site of interest

For ungauged rivers, the discharges from gauge sites were transferred to the site of interest using the following formula.

$$\text{Q site} = \left(\frac{\text{DA site}}{\text{DA gauge}}\right)^2 \times \text{Q gauged} \quad (7)$$

Results and Discussion

Testing stream flow and rainfall data for consistency

The double-mass curve analysis for the stream flow data in the case of this study is impossible because at least three gauging stations are necessary to check the consistency of one stream flow station to the other three stream flow stations. Due to the shortage of gauging stream flow stations, the missed value of two stations filled and used for a further application. The results of the double-mass curve analysis of the rainfall stations revealed that the rainfall recorded at the six gauging stations (Haramaya, Harar Indicative, Girawa, Kulubi, Hakim gara, and Kersa) of 30 years (1985-2014) are consistent with no significant change of slope on their respective plots, as presented in Figure 2.

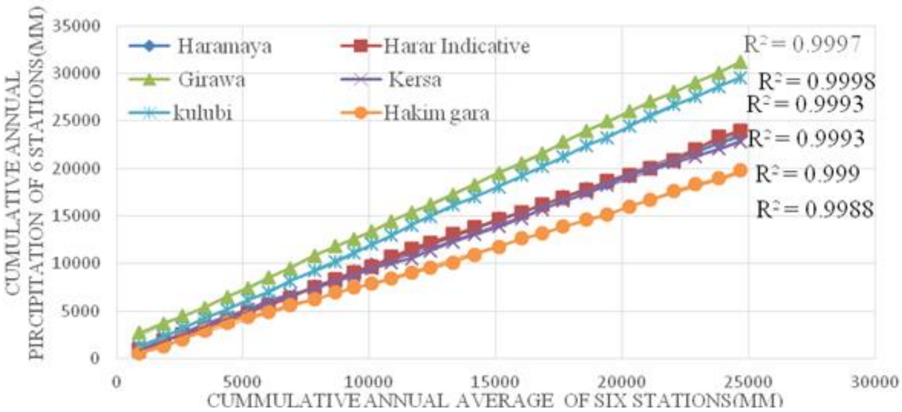

Figure 2: Double mass curve of six rainfall stations.

Water resources assessment

Water resources assessment relies on a full understanding of all the water flows and storages in the river basin or catchment under consideration. Prior to estimating stream-flows at the un-gauged sites from gauged sites, watersheds above both gauged and un-gauged sites were characterized. Taking the watershed similarities into account, stream flows at un-gauged sites were estimated from the gauged sites by applying the runoff coefficient method. These results are discussed under the following sub-sections:

Gauged and un-gauged watersheds similarities

Referring to Figures 3-8 and Tables 2 and 3, the sub-watersheds in Hamaressa sub-watershed with similar land cover, soil type, and slope range are identified and the results are presented in Table 3 and 4 of un-gauged sub-watersheds such as Maya kelo and Maya guda. Dawe sub-watershed are a similar land cover, soil type, and slope range with ungauged sub-watersheds such as Kersa guba, and Bululo.

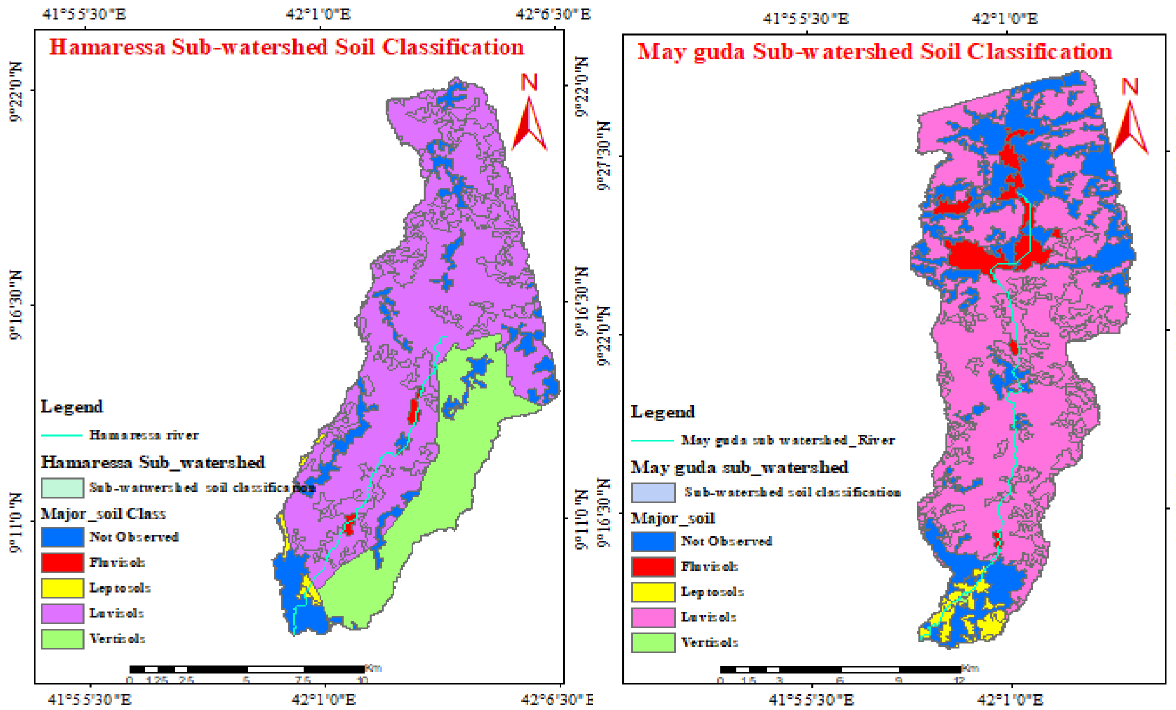

Figure 3: Double mass curve of six rainfall stations.

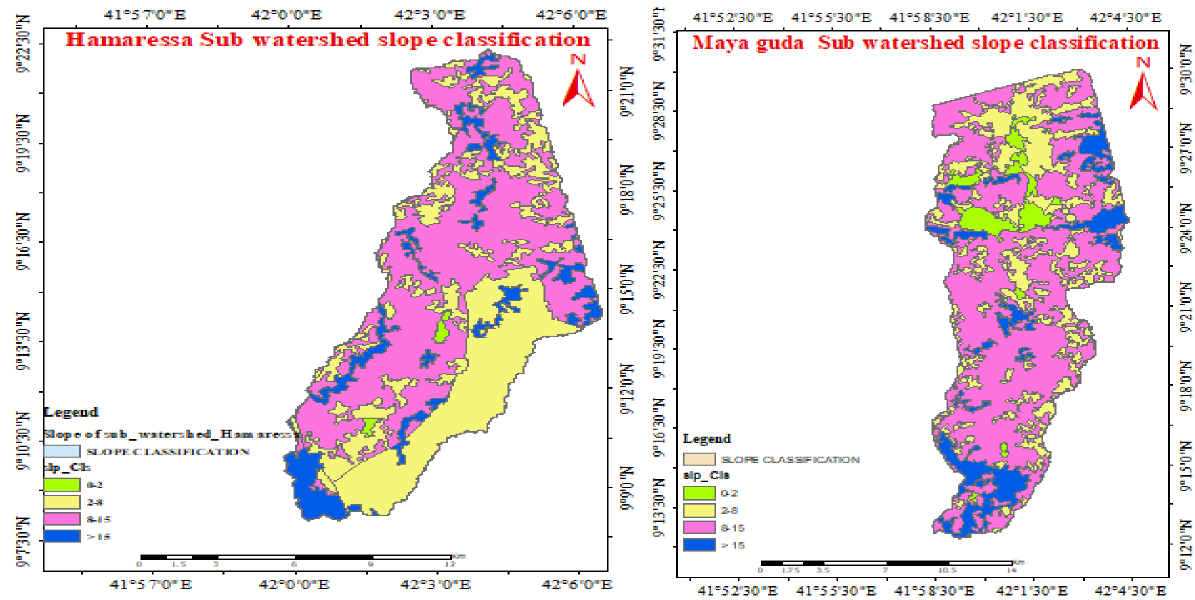

Figure 4: Slope map of Hamaressa, Maya kelo and Maya guda Sub-watershed.

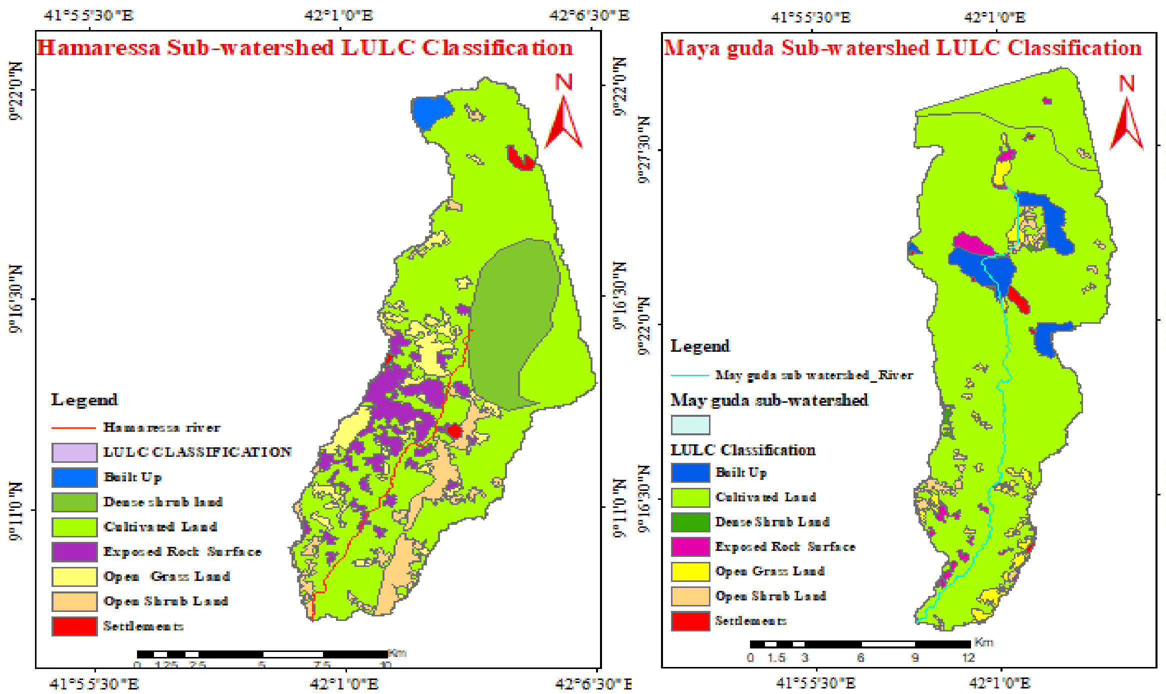

Figure 5: LULC map of Hamaressa, Maya guda and Maya kelo Sub-watershed.

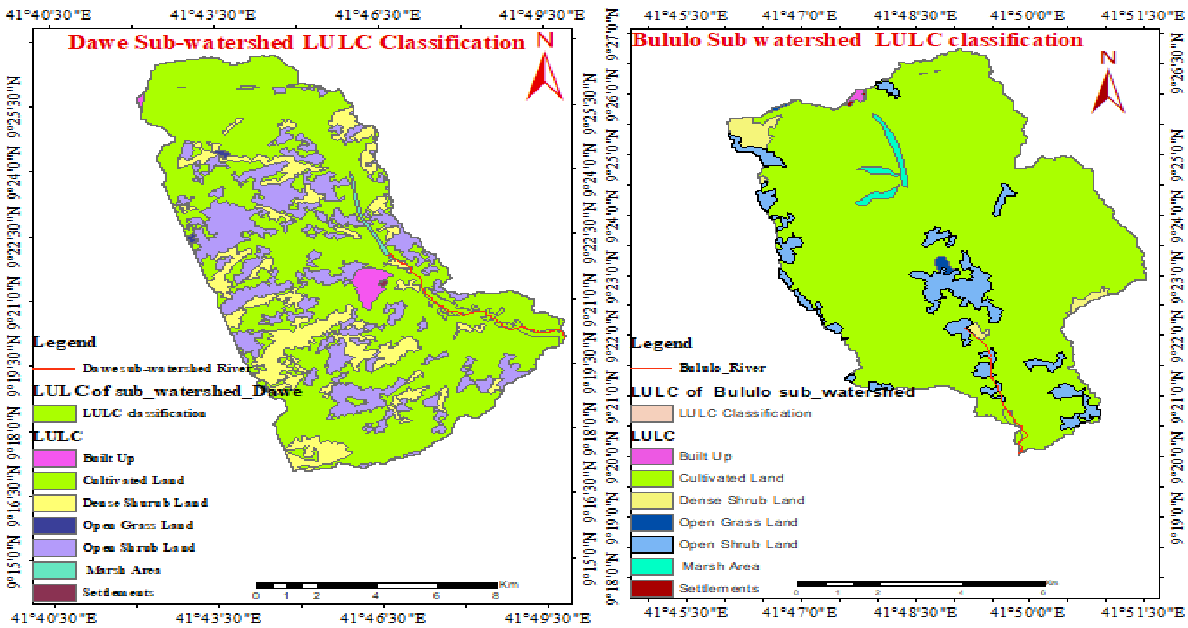

Figure 6: LULC map of Dawe and Bululo sub-watershed.

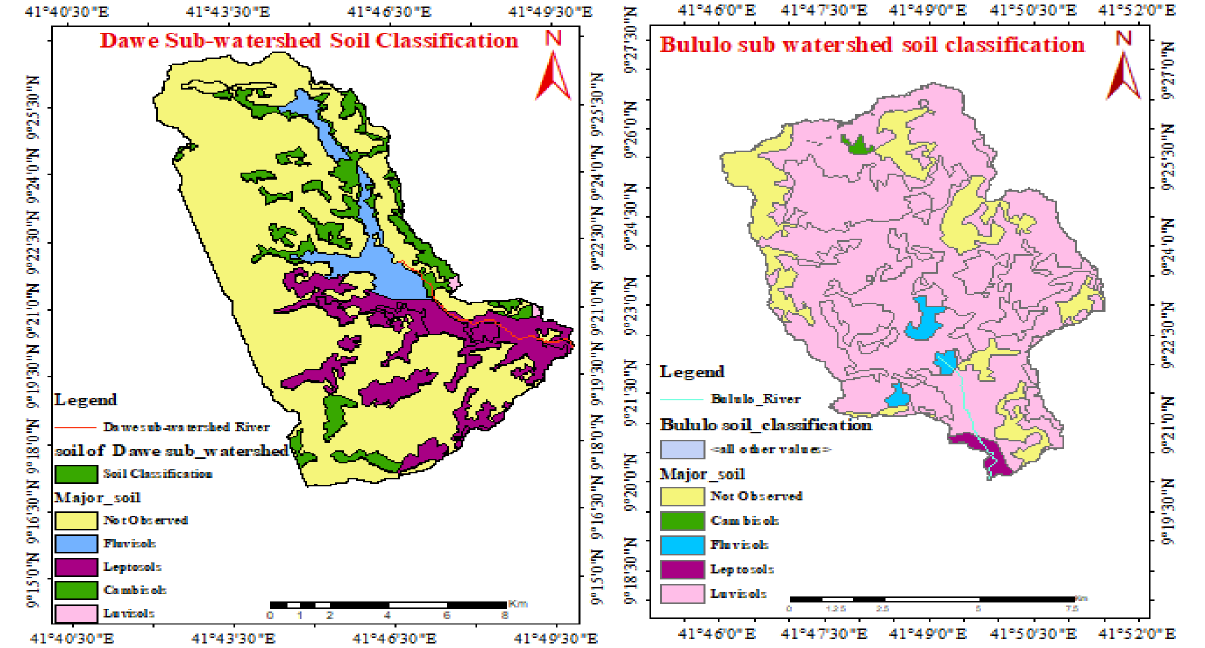

Figure 7: Soil map of Dawe and Bululo sub-watershed.

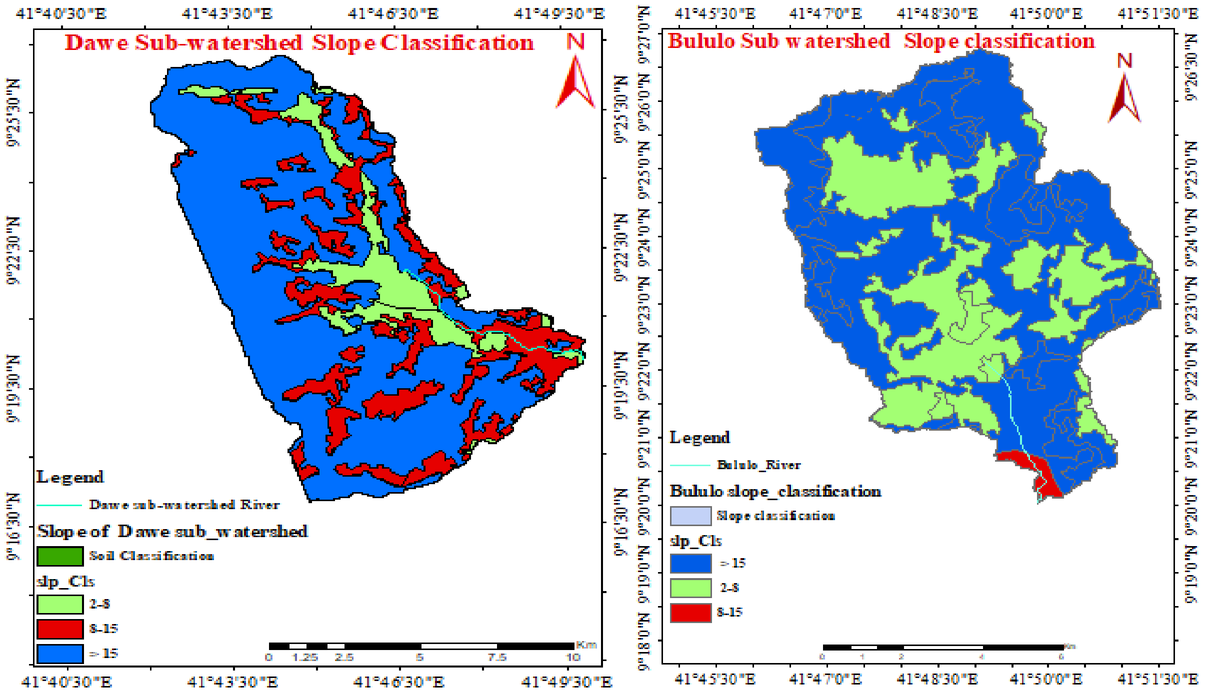

Figure 8: Slope map of Dawe and Bululo sub-watershed.

Table 2: Characteristics of watersheds above the gauged and un-gauged sites

Gauged sub watershed			Ungauged sub watershed	
Hamaressa			Maya kelo	Maya guda
Soil type	Area (ha)		Area (ha)	Area (ha)
Not observed	1787.69	Not observed	3136.72	6037.57
Fluvisols	100.24	Fluvisols	187.07	1276.31
Leptosols	142.62	Leptosols	7.46	668.44
Luvisols	10419.32	Luvisols	2166.65	16018.05
Vertisols	3330.24	Vertisols	7039.29	26.11
Slope range	Area (ha)		Area (ha)	Area (ha)
0-2	100.2	0-2	1272.8	1302.4
2-8	5989.3	2-8	2489.5	5735.2
8-15	7902.9	8-15	7472.5	13977.7
>15	1787.0	>15	3097.3	3011.2
Land use/cover	Area (ha)		Area (ha)	Area (ha)
Built up	192.3	Built up	292.3	1251.6
Dense shrub land	2107.6	Dense shrub land	59.3	97.7
Cultivated land	10070.2	Cultivated land	13413.1	20810.5
Exposed rock surface with scattered shrubs	1216.1	Exposed rock surface with scattered shrubs	121.3	208.0
Open grass land	1009.5	Open grass land	496.3	1099.0
Open shrub land	1172.9	Open shrub land	185.1	413.2
Settlements	118.5	Settlements	122.4	148.8

Table 3: Characteristics of watersheds above the gauged and un-gauged sites

Gauged sub watershed		Ungauged sub watershed		
Dawe			Kersa guba	Bululo
Soil type	Area (ha)		Area (ha)	Area (ha)
Not observed	8530.2	Not observed	3136.7	1129.6
Fluvisols	745.9	Fluvisols	187.1	134.4
Luvisols	1296.7	Luvisols	9205.9	5551.1
Leptosols	1983.6	Leptosols	7.5	85.1
Cambisols	33.2	Cambisols	28.1	25.9
Slope range	Area (ha)		Area (ha)	Area (ha)
2-8	1186.82	2-8	2166.7	2146.71
8-15	2839.31	8-15	7046.8	3515.3
> 15 (Dominant)	8530.18	>15 (Dominant)	3136.7	1129.59
Land use/cover	Area (ha)		Area (ha)	Area (ha)
Built up	152.3	Built up	292.3	10.3
Cultivated land	8025.0	Cultivated land	59.3	6284.6
Dense shrub land	1748.6	Dense shrub land	13413.1	116.4
Open grass land	19.7	Open grass land	121.3	32.0
Open shrub land	2530.9	Open shrub land	496.3	522.3
Seasonal marsh	40.9	Seasonal marsh	185.1	67.6
Settlements	5.7	Settlements	122.4	3.1

Physical similarity based on catchment characteristics

Tables 4 and 5 presents the catchments' physically similarity with each other, which was determined by the distance measure defined by this equation S = 1 – $Dist_{a,b}$ where, $Dist_{a,b} = \sqrt{\sum_{j=1}^{J} wj(Xa,j - Xb,j)}$. Hamaress and Maya Guda catchments are similar to each other with the S value of 0.97 and Hamaressa with Maya Kelo also similar catchment to each other with the S value of 0.94. Maya Guda and Maya Kelo were also very similar to each other with the S value 0.97. Four of the catchments, i.e. Hamaressa, Maya Kelo, and Maya Guda were similar with each other with S values greater than 0.90. Dawe and Bululo catchments are similar to each other with the S value of 0.98 and Dawe with Kersa guba also similar catchment to each other with the S value of 0.92. Bululo and Kersa guba were also very similar to each other with the S value 0.95. Dawe, Bululo and Kersa guba were physically similar catchments to each other. These indicates the discharge of gauged rivers (Hamaressa and Dawe) are possible to transfer to ungauged rivers (Maya guda, Maya kelo, Bululo and Kersa guba).

Table 4: Results of catchment physical similarity of Hamaressa gauged river with each other

Catchments'	Hamaressa	Maya kelo	Maya guda
Hamaressa	1	0.97	0.94
Maya kelo		1	0.97
Maya guda			1

Table 5: Results of catchment physical similarity of Dawe gauged river with each other

Catchments	Dawe	Bululo	Kersa guba
Dawe	1	0.98	0.92
Bululo		1	0.95
Kersa guba			1

Mean areal rainfall of sub-watersheds

Mean areal rainfall of sub-watersheds, which were used as input data to estimate stream flows in un-gauged sites, were calculated by Theissen polygon method using Arc GIS. All sub-watersheds are influenced by more than one rain gauge station's. Table 6 presents the stations drainage areas within the watersheds, stations' area fraction, and stations mean monthly rainfall contribution.

Table 6: Average monthly areal rainfall of the sub-watersheds

Stations	Stations drainage area (km²)	Station area fraction (%)	Stations monthly rainfall contribution (mm)											
Hamaressa sub-watershed														
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Girawa	26.90	17.0	3.2	2.9	13.9	27.4	25.2	19.9	23.6	28.5	21.1	9.3	3.9	1.9
Harar	37.88	24.0	3.2	5.4	19.2	32.1	22.1	14.1	24.6	29.9	26.6	11.9	3.9	2.6
Haramaya	0.21	0.1	0.01	0.02	0.06	0.11	0.09	0.05	0.11	0.15	0.12	0.05	0.02	0.02
Hakim gar	92.81	58.8	4.6	15.1	24.7	78.7	78.7	62.3	77.4	50.7	41.5	21.5	11.1	1.5
Total	157.8	100.0	11.1	23.5	57.9	138.3	126.1	96.4	125.7	109.2	89.3	42.8	19.0	5.9
Maya Guda sub-watershed														
Girawa	3.43	1.4	0.26	0.24	1.15	2.26	2.07	1.64	1.95	2.34	1.74	0.77	0.32	0.15
Haramaya	131.55	53.6	4.7	9.8	29.9	60.2	50.6	26.3	58.6	81.9	66.5	25.0	11.2	8.1
Kersa	0.30	0.1	0.02	0.01	0.07	0.10	0.08	0.07	0.11	0.14	0.10	0.07	0.02	0.01
Hakim gar	110.12	44.9	8.5	7.8	36.8	72.4	66.5	52.5	62.4	75.2	55.9	24.6	10.3	4.9
Total	245.40	100.0	13.4	17.8	67.8	134.9	119.3	80.5	123.1	159.5	124.2	50.4	21.9	13.2
Kersa guba sub-watershed														
Girawa	2.30	1.76	0.33	0.30	1.44	2.84	2.61	2.06	2.45	2.95	2.19	0.96	0.40	0.19
Kersa	116.52	89.09	16.9	12.8	62.2	84.7	67.2	58.3	94.7	127.1	87.3	61.6	19.6	10.4
Hakim gar	11.97	9.15	0.72	2.35	3.84	12.24	12.24	9.70	12.04	7.89	6.45	3.35	1.73	0.23
Total	130.79	100.00	17.9	15.5	67.5	99.8	82.1	70.0	109.2	137.9	96.0	65.9	21.7	10.8

Table 6: (continued)

Stations	Stations drainage area in (km^2)	Station area fraction(%)	Stations monthly rainfall contribution in (mm)											
Maya kelo sub-watershed														
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Girawa	0.96	0.66	0.12	0.11	0.54	1.06	0.98	0.77	0.92	1.10	0.82	0.36	0.15	0.07
Haramaya	6.01	4.14	0.36	0.76	2.31	4.65	3.91	2.03	4.53	6.33	5.13	1.93	0.87	0.63
Kersa	78.14	53.76	10.2	7.7	37.5	51.1	40.6	35.2	57.2	76.7	52.7	37.2	11.8	6.3
Hakim gar	60.24	41.45	3.3	10.7	17.4	55.5	55.5	43.9	54.5	35.7	29.2	15.2	7.8	1.0
Total	145.35	100.00	13.9	19.3	57.8	112.3	100.9	81.9	117.2	119.9	87.9	54.6	20.7	8.0
Dawe sub-watershed														
Kersa	15.22	11.58	2.2	1.7	8.1	11.0	8.7	7.6	12.3	16.5	11.4	8.0	2.5	1.3
Kulubi	116.26	88.42	21.3	18.8	74.2	126.1	70.6	80.6	137.5	185.2	112.3	32.7	17.8	25.5
Total	131.48	100.00	23.5	20.5	82.3	137.1	79.3	88.2	149.8	201.7	123.6	40.7	20.3	26.8
Bululo sub-watershed														
Kersa	61.78	87.99	16.6	12.6	61.4	83.5	66.3	57.5	93.5	125.4	86.2	60.8	19.3	10.2
Kulubi	8.43	12.01	2.9	2.6	10.1	17.1	9.6	11.0	18.7	25.1	15.3	4.4	2.4	3.5
Total	70.21	100.00	19.5	15.2	71.4	100.7	75.9	68.4	112.2	150.5	101.4	65.2	21.7	13.7

Stream flows at un-gauged sites

Tables 3 and 4 shows that the characteristics of watershed above the un-gauged sites on Maya guda, Maya kelo, Kersa guba, and Bululo rivers are similar with the watersheds above the gauged sites on Dawe River (near Gara) and Hamaressa river (near Harar). Similarly, the distances between these gauged and un-gauged sites were found to be less than 50 km and the length of records of streamflow data at Dawe and Hamaresa gauging sites were about 10 years, respectively. Hence, the requirements suggested by Goldsmith (2000) to use the runoff coefficient method were met and thus estimated mean monthly discharges at the un-gauged sites from gauged sites are presented in Table 7.

Table 7: Mean monthly stream flows of un-gauged river catchments estimated from gauged sites

River catchment name		Mean monthly flows ($m^3 s^{-1}$)											
Gauged river	Ungauged river	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dawe	Kersa gub.	1.9	2.0	2.1	4.0	4.0	4.4	4.5	4.3	4.6	3.1	1.3	2.1
	Bululo	1.3	1.4	1.4	2.7	2.7	3.0	3.1	3.0	3.2	2.1	1.8	1.4
Hamaresa	Maya gud.	5.4	4.9	8.3	9.7	9.7	9.4	9.2	8.3	7.9	7.0	7.4	6.7
	Maya kelo	3.9	3.6	6.1	7.1	7.1	6.9	6.7	6.1	5.7	5.1	5.4	4.9

Transferring discharges to sites of interest

The discharges at the site of the interest were obtained by transferring the river discharges at the gauged site to the site of interest on the same river. The site of interest, in this case, is referring to a site closer to and above the identified potential irrigable land. Hence, the area ratio method suggested by Awulachew (2001) was adopted and the results are presented in Table 8.

Irrigation potential of river catchments

Irrigation potential of the river catchments in the study area was obtained by comparing irrigation requirements of the identified land suitable for surface irrigation and the available mean monthly flows in the river catchments based on the method suggested by Asitatikie and Gebeyehu (2021).

Cropping pattern: once the crops have been selected, one can make up the seasonal cropping pattern indicating the place and the occupying area of each crop. When designing an irrigation scheme, the preparation of cropping program is the first step in calculating crop water requirements. Based on this, the capacity of the irrigation system and the area to be covered by the system can be determined, taking into consideration the water availability. A cropping program diagram as shown in Table 9 helps in establishing which crop will occupy what part of the available area during each season, also taking into consideration the crop rotation requirements.

Table 8: Mean monthly discharges ($m^3 s^{-1}$) at the sites of interest

Site-of interest	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dawe-at Mudena	1.9	2.0	2.1	4.0	4.0	4.4	4.5	4.3	4.6	3.1	2.6	2.1
Hamaresa at Gobale	4.1	3.8	2.3	7.4	7.4	7.2	7.1	6.4	6.0	5.3	5.7	5.2

Table 9: Crop calendar and cropping pattern

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maize			23							15		
Potato				01					02			
Sorghum						01				08		

Agronomic aspects of selected crops according to FAO (2001).

Potato: potatoes can grow in a wide range of soils, but the best soils are medium-textured loamy soils with good organic matter content. Heavy clays can become hard, producing misshapen tubers, although yield can be high. Optimum soil acidity is pH 5.0-5.5. Avoid applying lime to a potato crop, since this may cause a disease called potato scab. Lime should be applied to other crops before potatoes. Soil depth should be at least 60 cm. Tubers are not produced if temperatures are high at the critical time of tuber initiation or if the plants are killed by frost. Mean optimum temperatures for tuber production are 15-20°C. With temperatures above 32°C both tuber formation and yield are poor.

Maize: wide range of soils, well-drained, high organic matter, pH 5.0 and summer crop and temperature range 10-30°C, optimum 20-24°C.

Sorghum: the optimal growth temperature is 27-30°C, the water requirements is 500-600 mm, tolerant to salty and alkali soils (pH 5.0-8.5) and high mineral absorption efficiency.

Similarly, the irrigation requirements of the potato at all stages except mid-growth (September) are less than the available flow in the sub-watershed upstream of the sampling/diversion site. The irrigation water requirement of sorghum is higher in all stage except the initial and late stage of the development. The critical command areas were calculated according to Michael (2008) to grow these crops as shown in Tables 10 and 11 that can be reliably irrigated using the available flows.

The dependable flow at 95, 90, 85, 80, and 70% exceedance flow level are given below in Table 12. It is observed that much storage is required in the abstraction/diversion points for both maize and sorghum to fulfill the crop water requirement during rainy season or peak flood period.

Table 13 present gross irrigation demand of the three crops commonly grown in the study area (potato, sorghum and maize) and the available mean monthly flows of the corresponding river catchments. Results of these analyses showed that monthly irrigation requirements of maize are higher than the available mean monthly flows except the month of October and March. The monthly irrigation water requirement of sorghum crops is lower than the available flows in all the development stage of crops and the monthly irrigation requirement of potato is higher than the mean monthly available flow in mid and late stage of the crop development. As a result, the critical command areas were calculated according to Michael (2008) to grow these crops as shown in Table 13 that can be reliably irrigated using the available flows.

Table 10: Critical command area of maize

Critical month	FWS (L s^{-1} ha^{-1})	Potential command area (ha)	Critical command area (ha)
Nov	0.407		43475.0
Dec	0.881		25363.3
Jan	1.107	29497.6	31493.1
Feb	1.131		30807.8

Table 11: Critical command area of sorghum

Critical month	FWS (L s^{-1} ha^{-1})	Potential command area (ha)	Critical command area (ha)
Jun	0.804	17698.5	43940.5
Jul	0.62		56650.0

Table 12: Dependable flow at proposed site and irrigable area with % exceedance

% Exceedance	Flow (m^3 s^{-1})
95	18.1
90	19.0
80	22.5
70	23.1

Table 13: Comparing of irrigation demands and available flows of river catchments in the study area for maize, potato and sorghum

River name	Potential command area (ha)	Mean monthly discharge at the site of interest ($m^3 s^{-1}$)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dawe	58,995.15	1.9	2.0	2.1	4.0	4.0	4.4	4.5	4.3	4.6	3.1	2.6	2.1
Hamaresa		4.1	3.8	2.3	7.4	7.4	7.2	7.1	6.4	6.0	5.3	5.7	5.2
Kersa gub.		1.9	2.0	2.1	4.0	4.0	4.4	4.5	4.3	4.6	3.1	1.3	2.1
Bululo		1.3	1.4	1.4	2.7	2.7	3.0	3.1	3.0	3.2	2.1	1.8	1.4
Maya gud.		5.4	4.9	8.3	9.7	9.7	9.4	9.2	8.3	7.9	7.0	7.4	6.7
Maya kelo		3.9	3.6	6.1	7.1	7.1	6.9	6.7	6.1	5.7	5.1	5.4	4.9
	Total	18.6	17.7	22.4	34.9	34.9	35.4	35.1	32.3	32.0	25.7	24.2	22.5

Conclusions

Assessing available water resources for irrigation is very important to evaluate irrigation water requirement of selected crop in the study area. The total area coverage of the watershed that obtained through watershed delineation was 237,363.1 ha. The growth irrigation water requirement of maize crop in development, mid and late stage of the development exceeds the available flow and mid and late stage of potato crop. This does not mean that the total annual flow capacity is less than the irrigation water demand. There is a large amount of river flow as well as runoff during the peak flow periods, which is able to satisfy the demand of irrigated area. Stream flows at un-gauged sites were estimated using runoff coefficient method. However, future research should test other methods such as regional regression analysis, base flow correlation and development of unit hydrograph to estimate discharges at ungauged sites from gauged sites.

Potentially, irrigable land exceeds the available flows of water during the low flow periods but the mean total annual flow capacity is less than the irrigation water demand so, provision of storage reservoirs has to be implemented in the watershed to satisfy the crop water requirement during low flows. The total annual irrigation water potential/ annual available flow above abstraction site is 335.7 $m^3 s^{-1}$ or 2.9 hm^3.

Acknowledgments

The authors, we would like to express our deepest gratitude to Haramaya University and East Hararghe Districts for facilitating my field work.

References

Addor, N.; Melsen, L. A. Legacy, rather than adequacy, drives the selection of hydrological models. Water Resources Research, v. 55, n. 1, p. 378-390, 2019. https://doi.org/10.1029/2018WR022958

Albert, J. M. Hydraulic analysis and double mass curves of the Middle Rio Grande from

Table 13: (continued)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
						Crop wat requirement of maize						
Potential command area (58,995.15 ha)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total available flow ($m^3 s^{-1}$)	18.6	17.7	22.4	34.9	34.9	35.4	35.1	32.3	32.0	25.7	24.2	22.5
Total GIR ($m^3 s^{-1}$)	87.1	89.0	42.8	0.0	0.0	0.0	0.0	0.0	0.0	13.3	32.0	69.3
						Crop wat requirement of potato						
Potential command area (58,995.15 ha)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total available flow ($m^3 s^{-1}$)	18.6	17.7	22.4	34.9	34.9	35.4	35.1	32.3	32.0	25.7	24.2	22.5
Total GIR ($m^3 s^{-1}$)	0.0	0.0	0.0	0.0	21.3	63.3	48.7	11.4	2.8	0.0	0.0	0.0
						Crop wat requirement of sorghum						
Potential command area (58,995.15 ha)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total available flow ($m^3 s^{-1}$)	18.6	17.7	22.4	34.9	34.9	35.4	35.1	32.3	32.0	25.7	24.2	22.5
Total GIR ($m^3 s^{-1}$)	0.0	0.0	0.0	0.0	0.0	9.3	17.1	14.2	29.0	10.2	0.0	0.0

Cochiti to San Marcial, New Mexico. Fort Collins: Colorado State University, 2004. 207p. Masters Dissertation.

Alsayim, H. E.; El-Edaim, A. M. A.; Elamin, A. W. M.; Adam, A. B.; Abass, M. A-E. The field evaluation of center pivot irrigation system's performance under River Nile State conditions, Sudan. Water Resources and Irrigation Management, v. 11, n. 1-3, p. 1-7, 2022. https://doi.org/10.19149/wrim.v11i1-3.2300

Asitatikie, A. N.; Gebeyehu, W. Z. Assessment of hydrology and optimal water allocation under changing climate conditions: the case of Megech river sub basin reservoir, Upper Blue Nile Basin, Ethiopia. Modeling Earth Systems and Environment, v. 7, p. 2629-2642, 2021. https://doi.org/10.1007/s40808-020-01024-0

Awulachew, S. B. Investigation of water resources aimed at multi-objective development with respect to limited data situation: The case of Abaya-Chamo Basin, Ethiopia. Dresden: Technische Universitat Dresden, 2001. 265p. Doctoral thesis.

Awulachew, S. B.; Ayana, M. Performance of irrigation: An assessment at different scales in Ethiopia. Experimental Agriculture, v. 47, n. S1, p. 57-69, 2011. https://doi.org/10.1017/S0014479710000955

Babar, S.; Ramesh, H. Streamflow response to land use–land cover change over the Nethravathi River Basin, India. Journal of Hydrologic Engineering, v. 20, n. 10, 05015002, 2015. https://doi.org/10.1061/(ASCE)HE.1943-5584.0001177

Dai, A. Historical and future changes in stream flow and continental runoff: A review. In: Tang, Q.; Oki, T. (ed.). Terrestrial water cycle and climate change: natural and human-induced impacts. Geophysical Monograph, 221. 1st ed. New Jersey: John Wiley & Sons, Inc., 2016. p. 17-37. https://doi.org/10.1002/9781118971772.ch2

Dingman, S. L. Physical hydrology. 2nd ed. New Jersey: Prentice Hall, 2002. 646p.

FAO – Food and Agriculture Organization of the United Nations. Irrigation water management: Irrigation water needs. In: Brouwer, C.; Heibloem, M. (ed.). Rome: FAO, 1986. 102p. (Training manual no. 3).

FAO – Food and Agriculture Organization of the United Nations. Irrigation potential in Africa: A basin approach. Rome: FAO, 1997. 177p. (FAO Land and Water, Bulletin no. 4).

FAO - Food and Agriculture Organization of the United Nations. Adapting to climate change through land and water management in Eastern Africa: Results of pilot projects in Ethiopia, Kenya and Tanzania. Rome: FAO, 2014. 166p.

Gebreegziaber, Y. Assessment of water balance of lake Hwassa catchment, Ethiopia. Enschede: ITC Faculty Geo-Information Science and Earth Observation, 2004. 92p. Masters Dissertation.

Goldsmith, P. Review note on soil erosion assessment. (Unpublished project working paper), Zimbabwe and Tanzania, 2000.

Gurara, M. A.; Jilo, N. B.; Tolche, A. D. Impact of climate change on potential evapotranspiration and crop water requirement in Upper Wabe Bridge watershed, Wabe Shebele River Basin, Ethiopia. Journal of African Earth Sciences, v. 180, 104223, 2021. https://doi.org/10.1016/j.jafrearsci.2021.104

Li, Q.; Li, Z.; Chen, L.; Yao, C. Regionalization of coaxial correlation diagrams for the semi-humid and semi-arid catchments in Northern China. Proceedings of the International Association of Hydrological Sciences, v. 368, p. 317-322, 2015. https://doi.org/10.5194/piahs-368-317-2015

Makhlof, H. A. H.; Elamin, A. W. M.; Mohamed, M. A.; Adam, A. B.; Abdeldyim, A. M. Demarcation of groundwater quality for irrigation purposes in Sirte, Libya. Water Resources and Irrigation Management, v. 10, n. 1-3, p. 15-24, 2021. https://doi.org/10.19149/wrim.v10i1-3.2299

Michael, A. M. Irrigation theory and practice. 2nd ed. New Delhi: Vikas Publishing House Pvt. Ltd., 2008. 772p.

Neway, M. M.; Zegeye, M. B. The determinants of household willingness to pay for irrigation water: in the case of Northern Showa, Amhara Region, Ethiopia. Water Resources and Irrigation Management, v. 11, n. 1-3, p. 8-21, 2022. https://doi.org/10.19149/wrim.v11i1-3.2798

Oudin, L.; Andréassian, V.; Perrin, C.; Michel, C.; Le Moine, M. Spatial proximity, physical similarity, regression and ungaged catchments: A comparison of regionalization approaches based on 913 French catchments. Water Resources Research, v. 44, n. 3, W03413, 2008. https://doi.org/10.1029/2007WR006240

Parajka, J.; Merz, R.; Blöschl, G. A comparison of regionalization methods for catchment model parameters. Hydrology and Earth System Sciences, v. 9, n. 3, p. 157-171, 2005. https://doi.org/10.5194/hess-9-157-2005

Toth, E. Catchment classification based on characterisation of streamflow and precipitation time series. Hydrology and Earth System Sciences, v. 17, n. 3, p. 1149-1159, 2013. https://doi.org/10.5194/hess-17-1149-2013

Yarahmadi, J. The integration of satellite images, GIS and CROPWAT model to investigation of water balance in irrigated area: A case study of Salmas and Tassoj plain, Iran. Enschede: ITC Faculty Geo-Information Science and Earth Observation, 2003. 56p. Masters Dissertation.