Assessment of Surface Irrigation Potential Availability Using Gis in Gilgel Abbay Catchment; Ethiopia

Gashaw Sintayehu (gashawsintayehu774@gmail.com)
Woldia University
Edmealem Temesgen
Arba Minch University
Destaw Akili
Arba Minch University

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ASSESSMENT OF SURFACE IRRIGATION POTENTIAL AVAILABILITY USING GIS IN GILGEL ABBAY CATCHMENT; ETHIOPIA.

Gashaw Sintayehu[1*], Edmealem Temesgen [2], Destaw Akili[3]

[1]Department of Water Resources and Irrigation Engineering, Institute of Technology, Woldia University, P.O.Box 400, Woldia, Ethiopia, E-Mail: gashawsintayehu774@gmail.com; Tel.:+251-9-18-31-53-23

[2]Department of Water Resources and Irrigation Engineering, Water Technology Institute, Arba Minch University, Arba Minch, Ethiopia, E-Mail: edmetemetsegiayu@gmail.com; Tel.:+251-9-32_54_88_98

[3]Department of Water Resources and Irrigation Engineering, Water Technology Institute, Arba Minch University, Arba Minch, Ethiopia, E-Mail: destaw2112@gmail.com; Tel.: +251-9-09_49_98_48

ABSTRACT

Irrigation is an important investment for improving rural income through increased agricultural production. The expansion of irrigation and effectively manage agricultural water holds significant potential to enhance productivity and reduce vulnerability to the climactic volatility in any country. Investigation of available water resources and potentially irrigable land is essential for the development of irrigated agriculture. This study was concerned with the assessment of surface irrigation potential availability in the Gilgel Abay watershed by implementing Arc GIS 10.1. Assessment of land suitability for irrigation is essential for the long production of crops and food security of the ever-growing population, as well as for the efficient use of limited physical land resources in the studied area. This research focuses on the possibilities for catchment surface irrigation and a water-saving sowing time scenario. The physical and chemical properties of the soil, slope, LULC, distance from water sources (Proximity to water), and surface water resource availability were all considered while determining land suitability for surface irrigation. According to the results of the land suitability evaluation ratings based on quantitative and qualitative land suitability for surface irrigation, 22.59 percent (86,747.19 ha) of lands in the research region were in the high to marginally suitable classes, while 77.41 percent were in the non-suitable class (297,252.4 ha). For November, December, January, and February sowing time scenarios, total irrigation water demand is 5,927.5Mm^3, 370.2 Mm^3, 455.4 Mm^3, and 506.2 Mm^3 respectively accordingly to irrigate 86961.24ha of irrigable land for 10 selected and dominating crops. The most favorable sowing starting month, according to sowing time scenarios, is in December, in order to save water or use less water to irrigate all available irrigable land and to fulfill all selected and dominating crops in the research area. Therefore, as a result, this research will assist all participants in making irrigation investment decisions and identifying long-term irrigation investment prospects in the study area.

Key Words: Surface Irrigation, Land potential availability, GIS, Gilgel abbay

1. INTRODUCTION

Rapid Ethiopia population growth has placed incredible stress on the earth's natural resources. The population of Ethiopia is largely rural and depends on agriculture for their livelihoods, but agriculture has not kept pace with population growth leading to severe chronic malnutrition and hunger, and periodic crises induced by drought. Agriculture is the core foundation for Ethiopia's economy, growth, and long-term food security. It directly supports 85 percent of the population's livelihoods, accounting for over 43% of the country's gross domestic product (GDP) and contributing over 80 % of foreign exchange earnings (IWMI, 2010).

Ethiopia has an area of 5.3 Mha potential irrigable land, of which 3.7 Mha can be developed using surface water resources and 1.6 Mha using groundwater and rainwater management (Awulachew and Ayana, 2001). Ethiopia has a large potential of water resources for irrigation development. The large potential of water is categorized into 12 major river basins, with an annual runoff volume of 122 bm^3 of water. The government of Ethiopia is planning and focusing on agricultural production, especially irrigation development programs to solve food scarcity and develop the agro-industry. Additional future water demands for different uses will rise due to population growth. To improve sustainable agronomic water management, one has to know the limitations and suitability of the potential land for irrigation and the availability of water around the area.

Irrigation planning process requires integration of information about the suitability of the land, water and climatic conditions. Irrigation water supplies and their requirements are important physical factors in matching the available supply to the requirements. The physical and chemical land resources that have great contribution on evaluation of land suitability for specific use must also be evaluated on condition that water can be supplied to it. Land evaluation is related with the selection of suitable land, and suitable cropping, irrigation and management alternatives that are physically and financially practicable and economically viable (FAO, 1985). Analysis of irrigation land suitability is needed for various reasons in the study area, in which the community is highly reliant on agriculture. However, systematic land suitability assessment, current land use and irrigation land suitability description for potential natural resource is needed. Irrigation land suitability analysis is a prerequisite to achieve optimum utilization of the available land resources for sustainable agricultural production.

There are different estimates of the irrigation potential of the country, but not been satisfactorily resolved. Now a day Based on GIS application environments have been used for surface irrigation potential analysis on various case study sites around Ethiopia (e.g. ((Garuma 2021); (Asfaw *et al* ., 2019); (Negash W. and Girma N., 2017); (Sleshi *et al*, 2016);). However, in Gilgel Abbay watershed there is no study available that analyses the land suitability and crop sowing time variability for surface irrigation. The study conducted based on weighting the physical and chemical property of catchment for irrigation potential.

According to FAO, the irrigation potential of a river basin is assessed based on the suitability of soil characteristics, the slope, LULC, available water resources for irrigation (FAO, 2008). The pattern of water potential and land suitability is one of the indicators of irrigation development and make sustainability of yield production. Identification and mapping of surface irrigation potential is especially important in the study catchment area given. The pressing need to increase agricultural productivity to meet growing food demands; the growing risks of increased rainfall variability due to climate change in already water-limited agricultural systems, and the growing interest by local and regional policy and management bodies for evaluation of land capability for various land-use alternatives. Therefore, this study aimed to: (i) identify the land suitability of the Gilgel Abbay catchment; (ii) identify the surface water potential for surface irrigation; (iii) identify the land suitability for 10 administration district which are found in Gilgel Abbay catchment; (iv) Evaluate the sowing time variability scenario for 10 dominant crops in Gilgel Abbay catchment).

2. MATERIALS AND METHODS

2.1. Description of the study area

Gilgel Abbay catchment is located in West Gojjam and Awi Administrative Zones of the Amhara National Regional State (ANRS) of Ethiopia. The watershed area has 10 District' namely: Mecha, South-Achefer, Dangla, Sekela, Fagtalakuma, North-Achefer, Bahir-Dar zuria, Banja, Quarit, and Yilmanedensa between 10° 56' to 11°51'N latitude and 36°44' to 37°23'E longitudes. The catchment area of Gilgel Abbay River at the outlet to Lake Tana is 3840.25 km^2 and it is the largest tributary of Lake Tana basin, which accounts for around 30% of the total area of the basin. This catchment contributes to the largest inflow into Lake Tana.

The average elevation of Gilgel Abbay catchment is 2657m a.m.s.l. Most part of the study area are Woina Dega and the small part of the study catchment is the Dega Zone climate. The average annual rainfall of Gilgel Abbay River watershed is 1845mm. The main rainfall season that accounts for around 70-90% of the annual rainfall occurs from June to September. The study area is shown below in figure 1.

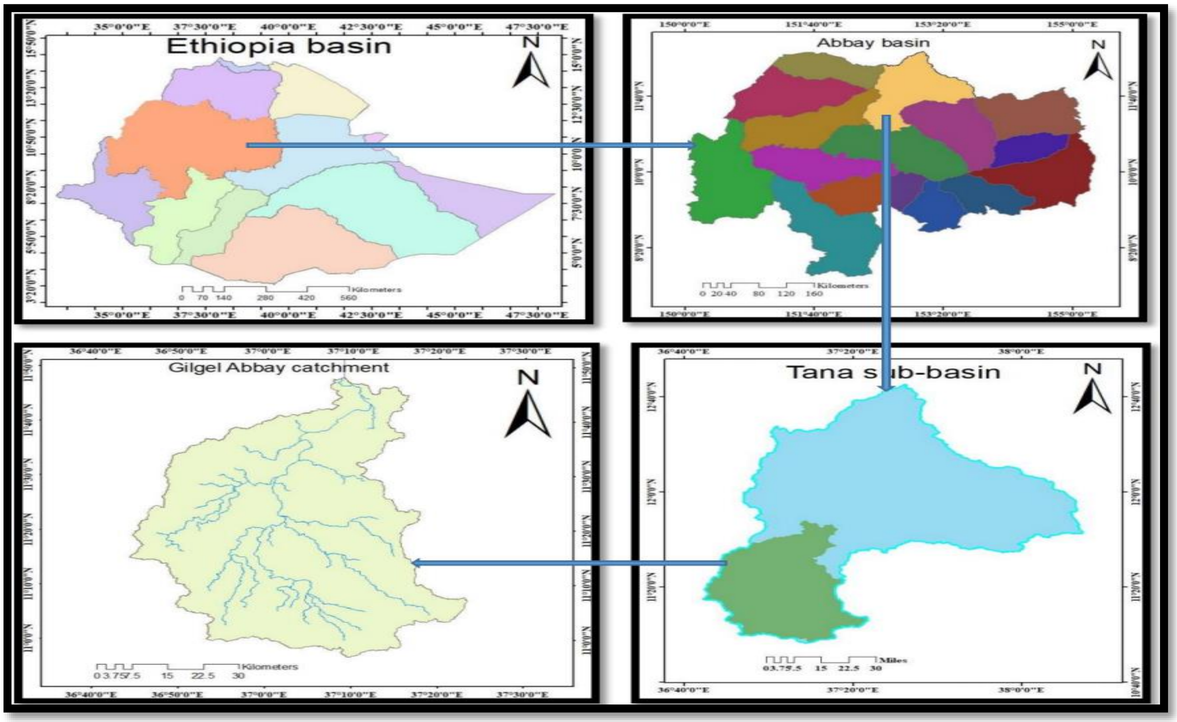

Figure 1: Study Area Map of Gilgel Abbay River.

Topography

The elevation of Gilgel Abbay catchment varies from 1787 to 3518m a.m.s.l. (SRTM). The higher elevation ranges are located at the Southeast corner while the remaining area is relatively uniform. From the slope map of the catchment area, around 70% of the catchment area falls in the slope range from 0-8% and 25% of the area falls in the slope range of 8-30%. The remaining 5% of the area has slope greater than 30%. The longest flow path of the river towards the outlet is 163.2 km.

Climate

The climate of Ethiopia can be classified in different ways including the Traditional, Koppen's, Throthwaite's, Rainfall regimes, and Agro-climatic zone classification systems. The most common used classification systems are the traditional and the agro-ecological zones. According to the traditional classification system, this mainly relies on altitude and temperature; there are five climatic zones namely: Wurch (cold climate at more than 3000 Mts. altitude), Dega (temperate like climate-highlands with 2500-3000Mts.altitude), Woina Dega (warm at 1500-2500 Mts. altitude), Kola (hot and arid type, less than 1500m in altitude), and Berha (hot and hyper-arid type) climate (NMSA, 2001).

Rainfall

The main rainy season in the study area is from June to September. Annual minimum and maximum rainfall ranges from 1076mm to 1420mm. The highest rainfall is recorded in the month of July. The minimum rainfall is observed in the month of January.

Temperature

In Gilgel Abbay watershed, the average temperature ranges in between 29.5and 7.9 C^{o}. Maximum temperature of the study area ranges from 29.5 to 23.74 C^{o}. Highest maximum temperature is observed in the month of March for all parts of the study area. The minimum temperature is recorded in the month of January, ranges from 12.5 to 7.9 C^{o}. The month of August is characterized by lowest maximum. The minimum temperature ranges from 12.5to 7.9 C^{o}.

Relative humidity

In Gilgel Abbay watershed, the average relative humidity ranges in between 37.5 and 85.7 %.The highest humidity is observed in the months of July and August. The lowest humidity is recorded in the month of February.

Wind Speed

The average annual wind speed of the study area ranges from 0.72to 1.2 m/s. The maximum wind speed is recorded in the month of May and Low wind speed is observed in the month of August.

Sunshine

The sunshine hours of the study area varies from 4.4 to 9.0 hours per day. The highest and lowest sunshine hours are recorded at January and July respectively.

Geology, soil types and land cover

Quaternary volcanic rocks overlay the older Tertiary volcanic over much of the Gilgel Abbay catchment boundary. The Quaternary volcanic sequence comprises blocky and fractured vesicular basalt, some basaltic breccia and tuffs perhaps as much as 200-300 m thick (SMEC, 2007).

According to FAO (2002) in this watershed seven main soil types are found which include, Luvisols, Fluvsisols, Alisols, Nitisols, Vertisols, Leptosols and Regosols. Generally, the soils types of this watershed area are characterized with shallow, moderate to deep and very deep in depth and sandy clay to clay texture types. The erodibility of these soils also varies from medium to very erodible characteristics. Each soil type explain and their property listed as follow:

Vertisols are deep to very deep, moderately well to poorly drained, very dark grey to dark yellowish brown in the topsoil, and clay textured throughout. The soils have large surface cracks in the dry season. Run-off formation from Vertisols is high and hence it is susceptible to erosion. The recent soils which are not developed are classified as Fluvisols and found in small extent in the watershed area. The shallow and very shallow soils are classified as Leptosols. Leptosols are found in relatively small areas in the watershed area. These are stony and rocky. The texture of Leptosols varies from sandy clay loam to clay and has excessive drainage characteristics.

Nitisols occupied about 2% of the watershed area. They are reddish brown to red clay soils. These soils are deep and have very good potential agriculture. The Nitisols of the area are intensely cultivated for annual crops.

Luvisols exist in bigger extent in the watershed area. These soils show textural differentiation with moderate to high clay content. These soils are almost intensively cultivated. The major red clay soils (Alisols) occur mainly on flat to rolling upland plain and flat to undulating land features. These are deep, well drained, permeable and medium textured soils. Regosols are found in very small extent in the watershed area. They are very deep and are imperfectly drained soils. The soils have very organic matter content and good inherent fertility status.

The main land covers in the Gilgel Abbay catchment are grassland, marshland, cultivated land, forest and grassland with frequent patches of shrubs, woods, trees, water and cultivated lands.

Drainage network

The total drainage area of the river is around 3840 km^2 and the longest flow path of river from source to the gauging station is Koga at Merawi which is found in Abbay River. The area upstream of this gauging station is 298 km^2 (from SRTM).

The longest flow path of Gilgel Abbay River from the source to the gauging station of Gilgel Abbay at Merawi is 84 km which is approximately half of the longest flow path of the river outlet of the catchment is around 163.2 km. There are two main gauging stations in the catchment which have continuous records for a long period. The first one is Gilgel Abbay at Merawi which is found close to Wetet Abbay town near the bridge of Gilgel Abbay River on the road from Addis Ababa to BahirDar. The area upstream of this gauging station is 1656 km^2 (from SRTM).

The other gauging station is Koga at Merawi which is found in Koga River before it joins the Gilgel Abbay River. The area upstream of this gauging station is 298 km2 (from SRTM). The longest flow path of Gilgel Abbay River from the source to the gauging station of Gilgel Abbay at Merawi is 84 km, which is approximately half of the longest flow path of the river.

2.2. Data Sources

Very necessary data's, which are very important for this study, are:

- ❖ **Digital Elevation Model**: were collected from the Ministry of Water, Irrigation, and Electricity of Ethiopia from the hydrology department.
- ❖ **Soil**: The digital soil map obtains from the Ministry of Water, Irrigation, and Electricity of Ethiopia from hydrology department FAO/UNESCO 2015.
- ❖ **Land use/land cover 2014**: downloading from Satellite image.
- ❖ **Meteorological data**: from the National Meteorology Agency, which are Precipitation, maximum and minimum Temperature, Sunshine hours, Relative humidity, and Wind speed were collected.
- ❖ **Hydrological data**: River flow data from the Ministry of Water Irrigation and Electricity.
- ❖ **Agronomic data**: Irrigation Calendar and Dominant Crop were collected from the ministry of agriculture.

2.3. Data Analysis

Agronomic data

From irrigation and agronomy department, 10 crops such as wheat, maize, barley, sorghum, potatoes, cabbage, sugarcane, banana, tomato and cotton crops were selected to estimate water requirement of the crop. Cropping calendar for these dominant crops was chosen as accustomed by local farmers and from the ministry of agriculture. The total growing period of crops does not surpass four to twelve months. Cropping pattern shown in table 1 below.

Table 1: Cropping patterns proposed for the study area only one sowing time scenario

No.	Crops	Length of growing period (days)	Growing period		Area coverage
			Planting date	Harvesting date	ha
1	Wheat	130	January 1	May 10	9696.124
2	Maize	125	January 1	Apr 30	10696.124
3	Barley	120	January 1	May 5	7696.124
4	Sorghum	125	January 1	May 5	6696.124
5	Banana	330	January 1	November 30	7796.124
6	potatoes	130	January 1	May 10	4986.124
7	cabbage	170	January 1	Jun 20	8696.124
8	Cotton	200	January 1	July 20	1696.124
9	Tomato	150	January 1	May 30	7696.124
10	sugarcane	360	January 1	December 30	8296.124

Source: Edmealem T. and Gashaw S. (2018) assessment of surface water and cultivatable land resources Potential for surface irrigation in gilgel abbay catchment.

Meteorological data

Agricultural activities and water potential are closely related to the temporal and spatial patterns of climatic variables such as rainfall, temperature, relative humidity, wind speed and sunshine hours and success of surface water potential strongly depends on climatic situation of an area. Therefore, in this paper all climatic variables should be considered, to satisfy the objectives.

These data were collected from Ethiopian national meteorological agency. Even though there are 8 climate stations in and nearby of the watershed and only five stations in and around the Gilgel abbay catchment, such as Adet, Bahir Dar, Dangla, Abay-shelko and Enjibara stations of daily climate data for 29 years were selected, because others station were not selected due to short record length are shown below in figure 2.

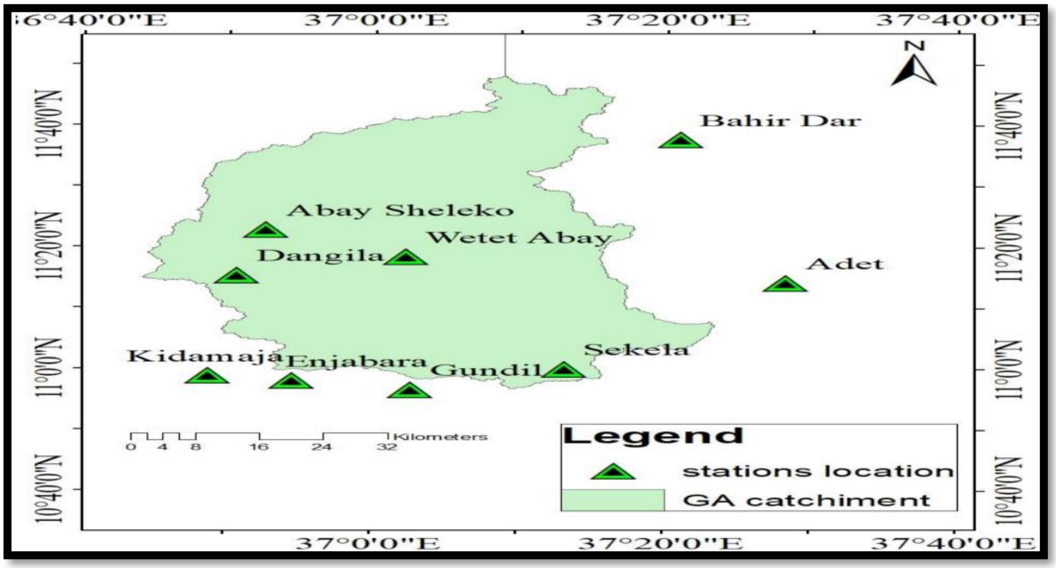

Figure 2: All climate stations in the watershed

Filling missing rainfall data

The main factors responsible for gaps and inconsistencies in available time series data include monitoring stations relocations, changes in instrumentation, changes of the surroundings, instrumental inaccuracies and changes of observational and calculation procedures (Richards, H. 1998). If data gaps are big, incomplete time series may hide the pattern of the data, and they may considerably distort the results of any statistical analysis. Filling the gaps in daily climate data is therefore a crucial issue. A way to redress the issue in existing time series data is infilling the gaps using one of the many available techniques. For this study, the missing values of daily rainfall recorded were completed by using the normal ratio method provided in Eq. (1), whereas air temperature, relative humidity, sunshine hours, wind velocity and hydrological data were corrected with linear regression methods.

Linear regression: Linear Regression is a process that allows us to make predictions about variable "Y" based on knowledge we have about variable "X". There are two lines of regression that of Y on X and X on Y. The line of regression of Y on X is given by $\mathbf{Y = a + bX}$ .where: a and b are unknown constants known as intercept and slope of the equation. This is used to predict the unknown value of variable Y when value of variable X is known. On the other hand, the line of regression of X on Y is given by $\boldsymbol{X = c + dY}$ which is used to predict the unknown value of variable X using the known value of variable Y. This is done by filling method gives poor results when the climate variable under analysis has a high spatial variability. Hence, in order to reduce this effect, those stations that are less important due to their distant location from the border of the watershed were used for filling purpose with their corresponding nearby stations.

Normal ratio method: This method is used if any surrounding gauges have the normal annual precipitation exceeding 10% of the considered gauge. If all (not some) value of normal annual precipitation of surrounding gauges lies within 10% range the arithmetic mean method would be used. First, we will determine that weather arithmetic mean or normal ratio method is to be applied. Therefore, since some value of normal annual precipitation of neighboring stations is beyond 10% range normal ratio method was applied.

The missing data are estimated by:

$$Px = \frac{Nx}{n} * \left(\frac{P1}{N1} + \frac{P2}{N2} + \frac{P3}{N3} + \frac{P4}{N4}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (1)$$

Where: - Px = missing rainfall data at station x, Nx = missing data station’s normal annual rainfall, (N1, N2, N3 and N4 = normal annual rainfall at stations i, P1, P2, P3 and P4 = precipitation at surrounding gauges station and n is the number of nearby gauges). Moreover, to calculate percent of difference to decide whether to use arithmetic mean or normal ratio method, the following equation has been used.

$$\text{percent of difference} = \left(\frac{Nx - Ni}{Nx}\right) * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (2)$$

In which Nx is the normal annual rainfall amount from the missing data station and Ni is the normal annual rainfall amount from the one of the nearby stations (Richard H., 1998). For this study as given Table 2 below the normal annual precipitation of the five stations is greater than 10%. Therefore, the normal ratio method has been applied to fill the missing data’s.

Table 2: Present of normal annual precipitation of the index stations.

No.	Station Name	Data type	Missed data (%)
1	Adet	Rainfall	3.95
2	Bahirdar	Rainfall	4.94
3	Dangila	Rainfall	5.198
4	Abbaysheleko	Rainfall	3.61

5	Enjibara	Rainfall	7.75
	Average		5.09

Source: Edmealem T. and Gashaw S. (2018) assessment of surface water and cultivatable land resources Potential for surface irrigation in Gilgel abbay catchment.

Consistency of rainfall

Before precipitation records are used in such studies, they should be tested to ensure that any trends detected are due to meteorological causes and not to changes in gage location, in exposure, or in observational methods. If the changes detected are not due to meteorological causes, a precipitation record can usually be adjusted by coefficients determined from the double-mass curve using equation (3).

The consistency of rain fall data was checked using double mass curve analysis through plotting the graph of cumulative rainfall collected against the cumulative average records collected at the selected stations in the same periods. The double-mass curve method was applied for consistency in this study as shown in figure 3.

$$Pcx = Px * \left(\frac{Mc}{M}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (3)$$

Where Pcx is corrected precipitation at any time period, Px is the original recorded precipitation, Mc is corrected slope of double mass curve and M is original slope of double mass curve. According to the double mass curves, since the stations used in this study has not undergone significant breaks in their slope all the stations were found to be consistent for the period of study (Figure 3).

By adjusting the consistency value of proportionally, double mass curve plot was made for all of the five stations. As it can be shown in Figure 3, all the stations were found to be consistent and the correlation coefficient of the annual cumulative rainfall of each station with average annual cumulative rainfall values of all the five stations is well.

To check the degree of consistency, Nemec (1973) provided the following value of the coefficient of correlation as follows:

r = 1: direct linear correlation,

$0.6 \leq r < 1$: good direct correlation,

$-0.6 < r < 0$: insufficient – reciprocal correlation,

$-1 < r < 0.6$: good reciprocal correlation and

$r = -1$: reciprocal linear correlation.

The double mass curve to check the consistency of a rainfall data are described below.

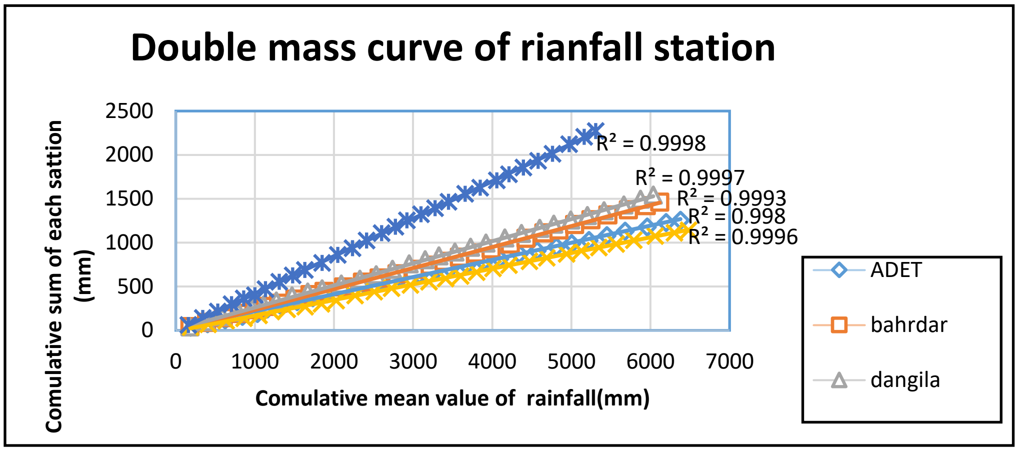

Figure 3: Double mass curve of all stations used for the study.

2.3. Estimating discharges at un-gauged sites from gauged sites

The rainfall data analysis results, together with discharges from gauged sites, were used to estimate the stream-flow at the un-gauged sites in the study area. Since only ithe rrigation potential of perennial rivers were considered in this study, a long term average of streamflow at gauged sites and mean monthly areal rainfall of the sites were used to estimate the discharges at un-gauged sites. This was performed by applying runoff coefficient of the gauged sites to un-gauged sites (FAO, 1997; Goldsmith, 2000 and DFID, 2004).

According to Goldsmith (2000) and DFID (2004), to estimate mean monthly runoff volume of ungauged 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 50km and a minimum 10 years mean monthly river flow at the gauged sites should be available. Based on these criteria, the gauged and ungauged river catchments soil, slope and land cover maps were derived using FAO (1997) digital soil map of East Africa, DEM and SPOT5 satellite image, respectively.

$$Qungaged = \left(\frac{DA\ ungaged}{DA\ gauged}\right)^n * Qgauged \ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(4)$$

Where: $Q_{ungauged}$= Discharge at site of interest (m3/s).

$DA_{ungauged}$ = Discharge area at site of interest (m2).

DA_{gauged} = Drainage area at gauged site (m2).

Q_{gauged} = discharge at gauged site (m3/s) and n = exponent b/n 0.6 and 1

If the DA ungauged should be 20% of the DA gauged ($0.6 \leq \frac{DAungauged}{DAgauge} \leq 1.2$), n value equal to 1 unless n equal to 0.6. The stream flow calculated using above equation for un-gauged sites were used to estimate either adequacy for the potential irrigable sites.

Gauged and un-gauged watersheds similarities

Gilgel Abbay watershed have almost similar properties in both gauged and ungauged watershed with similar slope range, soil type, and land cover are identified and the results are Presented in table 3.

Table 3: Characteristics of watersheds in both gauged and un-gauged sites.

Suitability parameters	Gauged watersheds	Un-gauged watersheds
Slope Range	0-2%	0-2%
	2-5%	2-5%
	5-8%	5-8%
	>8%	>8%
Soil type	Eutric Fluvisol	Eutric Fluvisol
	Eutric Leptosols	Eutric Leptosols
	Eutric Vertisols	Eutric Vertisols
	Haplic Alisols	Haplic Alisols
	Haplic Luvisols	Haplic Luvisols
	Urban	Urban
LULC	Grassland	Grassland
	Forest Land	Forest Land
	Agricultural Land	Agricultural Land
	Bare Land	Bare Land
	Urban Land	Urban Land
	Shrub Land	Shrub Land

Source: Edmealem T. and Gashaw S. (2018) assessment of surface water and cultivatable land resources Potential for surface irrigation in gilgel abbay catchment.

2.4. Crop water requirement

Water requirement is the quantity of water, regardless of its source, required by a crop or diversified patterns of crops in a given period of time for its normal growth under field conditions at a place. (Sileshi *et al*, 2007).

Water requirement includes the losses due to evapotranspiration (ET) or consumptive use (CU) plus the losses during the application of irrigation water (unavoidable losses) and the quantity of water required for special operations such as land preparation, transplanting, leaching, etc.

$$\mathrm{WR} = \mathrm{CU} + \text{Application loss} \ldots \ldots \ldots \ldots 5$$

The combination of two processes whereby liquid water is lost on the one hand from the soil surface by evaporation and on the other hand, from the crop by transpiration is referred to as evapotranspiration.

Consumptive use (CU) is the evapotranspiration from a vegetated area plus the water used directly by plants in the metabolic process of building the plant tissues. As the water used in the metabolic process is negligibly smaller (usually, less than 1% of the total loss), it is the usual practice to neglect the difference between evapotranspiration and consumptive use and the two terms are generally used synonymously.

Water requirement is, therefore a “demand” and the “supply” would consist of contributions from any of the sources of water, the major source being the irrigation water (IR) and effective rainfall (ER) and soil profile contribution (S) including that from shallow water tables.

$$\mathrm{WR} = \mathrm{IR} + \mathrm{ER} + \mathrm{S} \ldots \ldots \ldots \ldots 6$$

The field irrigation requirement of a crop therefore, refers to the water requirement of crops, exclusive of effective rainfall and contribution from the soil profile, and given as:

$$\mathrm{IR} = \mathrm{WR} - (\mathrm{ER} + \mathrm{S}) \ldots \ldots \ldots \ldots 7$$

Gross irrigation water demand: Irrigation water requirement of each the selected crops were calculated using CROPWAT.8 software. For the calculation of ETc/CWR, data from Dangila meteorological station was used.

$$GIWR = \left(\frac{NIWR}{over\ all\ efficency * time}\right) * area \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (8)$$

Above equation 8 show that GIWR is calculate in discharge but depth of GIWR is calculated based on the following formula:

$$GIWR = \left(\frac{NIWR}{over\ all\ efficency}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (4.1)$$

Where: NIWR-net irrigation water requirmrnt.

Based on the Minimum available water, the effective irrigable area can be estimated in each month and at different scenario in the following equation.

$$A(ha) = \frac{Acrop * E * low\ flow}{GIWR} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (9)$$

A_{crop} = Area covered by crop (ha)

A (ha) = irrigated Area

E = irrigation efficiency

GIWR = Grosse irrigation water requirement (m^3/s)

Evapotranspiration (ET): Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes. Apart from the water availability in the top soil, the evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil surface. This fraction decreases over the growing period as the crop developed and the crop canopy shades more and more of the ground area. When the crop is small, water is predominately lost by soil evaporation, but once the crop is well developed and completely covers the soil, transpiration becomes the main process.

The evapotranspiration (ET) rate is normally expressed in millimeters (mm) per unit time. The rate expresses the amount of water lost from a cropped surface in units of water depth. The time unit can be an hour, day, decade, month, or even an entire growing period of years. The amount of water required to compensate the evapotranspiration loss from the cropped field is defined as a crop water requirement. Although the values for crop evapotranspiration and crop water requirement are identical, the crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration.

Reference crop evapotranspiration (ETO): The evapotranspiration rate from a reference surface, not short of water, is called the ETo (Reference Crop Evapotranspiration). The reference surface is a hypothetical grass reference crop with specific characteristics. The concept of the reference evapotranspiration was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development, and management practices. As water is abundantly available at the reference evapotranspiration surface, soil factors do not affect ET. Relating ET to a specific surface provides a reference to which ET from other surfaces can be related.

The only factors affecting ETO are climatic parameters. Consequently, ETO is a climatic parameter and can be computed from weather data. ETO expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors. The FAO Penman- Monteith method is recommended as the sole method to determine ETO. Moreover, procedures have been developed for estimating missing climatic parameters.

$$ETO = \frac{0.408\Delta(Rn - G) + \frac{900\gamma}{T + 27.3} * U2(es - ea)}{\Delta + \gamma(1 + 0.34U2)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 10$$

Where:

ET_O reference evapotranspiration [mm/day]

Rn net radiation at the crop surface [MJ/day m2]

G soil heat flux density [MJ/day m2]

T Mean daily air temperature at 2m height [O C]

U_2 wind speed at 2m height [m/s] es saturation vapor pressure [k Pa]

Ea actual vapor pressure [k Pa]

es –ea saturation vapor pressure deficit [k Pa]

Δ Slope vapor pressure curve [k Pa/ O C]

γ Psychrometric constant [k Pa/ O C]

Crop evapotranspiration under standard condition: The ETc (Crop Evapotranspiration under standard condition) is the evapotranspiration from disease free, well-fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions.

Crop evapotranspiration can be calculated from climatic data and by integrating directly the crop resistance and air resistance factors in the Penman-Monteith approach. As there is still a considerable lack of information for different crops, the Penman-Monteith method is used for the estimation of the standard reference crop to determine its evapotranspiration rate.

$$\mathrm{ETc} = \mathrm{Kc} * \mathrm{ETO} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 11$$

Irrigation efficiencies: Efficiency is the ration of the water output to the water input, and is usually expressed as a percentage. Input minus output is nothing but losses, and hence, if losses are more, the output is less and therefore, efficiency is less. To calculate gross irrigation requirement of crops at specified potential irrigable sites, irrigation efficiencies of 54% is used for surface irrigation (FAO, 1989,).

Consumptive irrigation requirement: It is an amount of irrigation water required in order to meet the evapotranspiration needs of the crop during its full growth, mathematically:

$$\mathrm{CIR} = \mathrm{CU} - \mathrm{RE} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 12$$

Net irrigation requirement: It is an amount of irrigation water required in order to meet the evapotranspiration need of the crop as well as other needs such as leaching. Therefore,

$$\mathrm{NIR} = \mathrm{CU} - \mathrm{RE} + \mathrm{loss} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 13$$

Effective precipitation (RE): Out of given precipitation, the only effective part is available for plant use, which is stored as available water in the soil within the root zones of crop grown. The water, which flows away as surface runoff, or percolate below the root zone is lost. Effective rainfall depends on meteorological and non-meteorological parameters.

Meteorological parameters are characteristics of rainfall (amount, frequency, intensity and distribution over the area and in time), air temperature, radiation, relative humidity and wind velocity. Non-meteorological parameters are land characteristics (topography, slope, type of use), soil type (depth, texture, structure, bulk density, salt and organic matter content), management factors (type of tillage, degree of leveling, use of soil conditioners, type of layout, bund, terracing, ridging), crops (nature of crops, depth of root system, degree of ground cover, stage of growth, crop rotations) and characteristics of groundwater and irrigation channels (Valher, 2013).

2.5. Suitability assessment method

The investigation of suitable sites for surface irrigation was carried out based on slope, LULC, physical and chemical soil property, and distance from the source to the water supply. From several sources for the study areas, GIS raster datasets indicators were gathered. Land suitability for agriculture can be classified into five categories: highly suitable, moderately suitable, marginally suitable, currently unsuitable, and permanently unsuitable (FAO, 1996). In this study, we customized and reclassified each raster criteria layer into four categories with associated suitability: (S1 = highly suitable; S2 = moderately suitable; S3 = marginally suitable, and N = unsuitable). The ‘unsuitable’ category represents the ‘permanently unsuitable’ and ‘currently unsuitable’ category of FAO.

Slope suitability: is one of the most important topographic factors which influence on surface irrigation practices. The slope suitability maps of the study area were generated from the Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) data of 30m resolution available on Google Earth (Moore and Hansen, 2011); (Gorelick, 2013). According to FAO (1999), the slope was classified into four groups. These slope suitability classes were S1 (<2%), S2 (2–5%), S3 (5–8%), and N (>8%), representing highly suitable, moderately suitable, marginally suitable, and not suitable for surface irrigation, respectively.

Soil characteristics suitability: are one of the most important factors in irrigation land assessment development (Dominati et al, 2016); (Bonfante, and Bouma, 2015); (Juhos et al, 2016). In this study, soil stoniness, depth of soil, soil drainage, soil type, soil texture, Salinity, Alkalinity, and Soil reaction (pH) are taken as indicators to assess general soil suitability for agriculture. The soil properties used here were standardized for land suitability assessment as shown in Table 4. These soil characteristics were categorized based on FAO soil classification and characterization guide for agricultural suitability by FAO (FAO, 1990).

Table 4. Factor rating for suitability of chemical and property soil.

Soil property Factors	Soil Suitability class			
	S1	S2	S3	N
Soil type	Nitisols, luvisols, ,cambisols phaeozems	vertisols, alisols	histosols ,liptosols	_
Soil stoniness (%)	0–3	3–15	15–50	>50
Soil texture	C, SiC, SC	Si-SCL	SL, LS, FS	Coarse Sand
Soil depth	>90	50–90	20–50	0–20
Soil drainage	Well	Moderately	Imperfectly	Poorly
Salinity (EC in ds/m)	<4	4 – 8	18 – 12	>12
pH	5.0 - 8.5	4.5 - 5.0	4.0 - 4.5	< 4.0
		8.5 - 9.0	9.0 - 9.2	> 9.2
Alkalinity (ESP)	< 10	10 – 15	15 - 20	> 20

Soil texture: C = Clay, SC = Sandy Clay, SiC = Silty Clay, Si = Silt, L = Loam, CL = Clay Loam, SiCL = Silty Clay Loam, SCL = Sandy Clay Loam, SiL = Silty Loam, SL = Sandy Loam and soil type: nitisols (NS), luvisols (LS), cambisols (CS), phaeozems (PS), vertisols (VS), alisols (AS), histosols (HS), liptosols (LpS).

Source: (FAO, (1991)) guideline for the land evaluation and modified by the OWWDSE land evaluation team based on practical observation.

Land cover/land use: The provision of identifying land suitability for irrigation with precise and quantitative economic evaluation. The land use land cover description was shown below in Table 2. Jaruntorn et al, (2004) describes matching of existing land cover/use with topographic to evaluate land suitability for irrigation are shown below in Table 5.

Table 5. Land use/land cover suitability criteria.

Category	Name	Description of land cover types
S1	Highly suitable	Cultivated—dominantly, moderately Grassland—open, bushed, shrubbed Bush land—open, riparian
S2	Moderately suitable	Woodland—open, riparian Bush land—dense
S3	Marginal suitable	Forest—open Cultivated—Irrigation, state farm
N	Not suitable	Woodland—dense Bamboo Urban area

Source: (FAO, (1991)) guideline for the land evaluation and modified by the OWWDSE land evaluation team based on practical observation.

Proximity to water: Spatial proximities to water sources were computed using the spatial overlay of GIS layers. Influences of distance parameters on agricultural land suitability were estimated based on literature and field observation (Wale et al, 2013); (Bizuwerk et al, 2005). The four proximity to water suitability classes were S1 (<1.5km), S2 (1.5–3km), S3 (3–5km), and N (>5km), representing highly suitable, moderately suitable, marginally suitable, and not suitable for surface irrigation, respectively.

Identifying surface water and irrigation potential: The availability of surface water for surface irrigation potential was estimated for the whole crop growth period. The maximum and minimum flows were estimated in the river basin, which was important in identifying the irrigation potential of the river basin by comparing it with the corresponding irrigation water requirement. Gross irrigation demand for ten dominant crops and the available mean monthly flows of the river basins were estimated and compared. The measured streamflow data of the Gilgel Abbay River catchment were used to estimate surface water yield.

2.6. Conceptual Framework

After all the necessary data were collected from different data sources, further analysis was carried out for each physical land suitability factor to evaluate the suitability of the suggested land for surface irrigation, and crop sowing time scenario. To address the objectives starting from the data collection up to the final result of the study is presented as shown here below from figure 4. the This schematic diagram shows the methdology and the parameters we use.

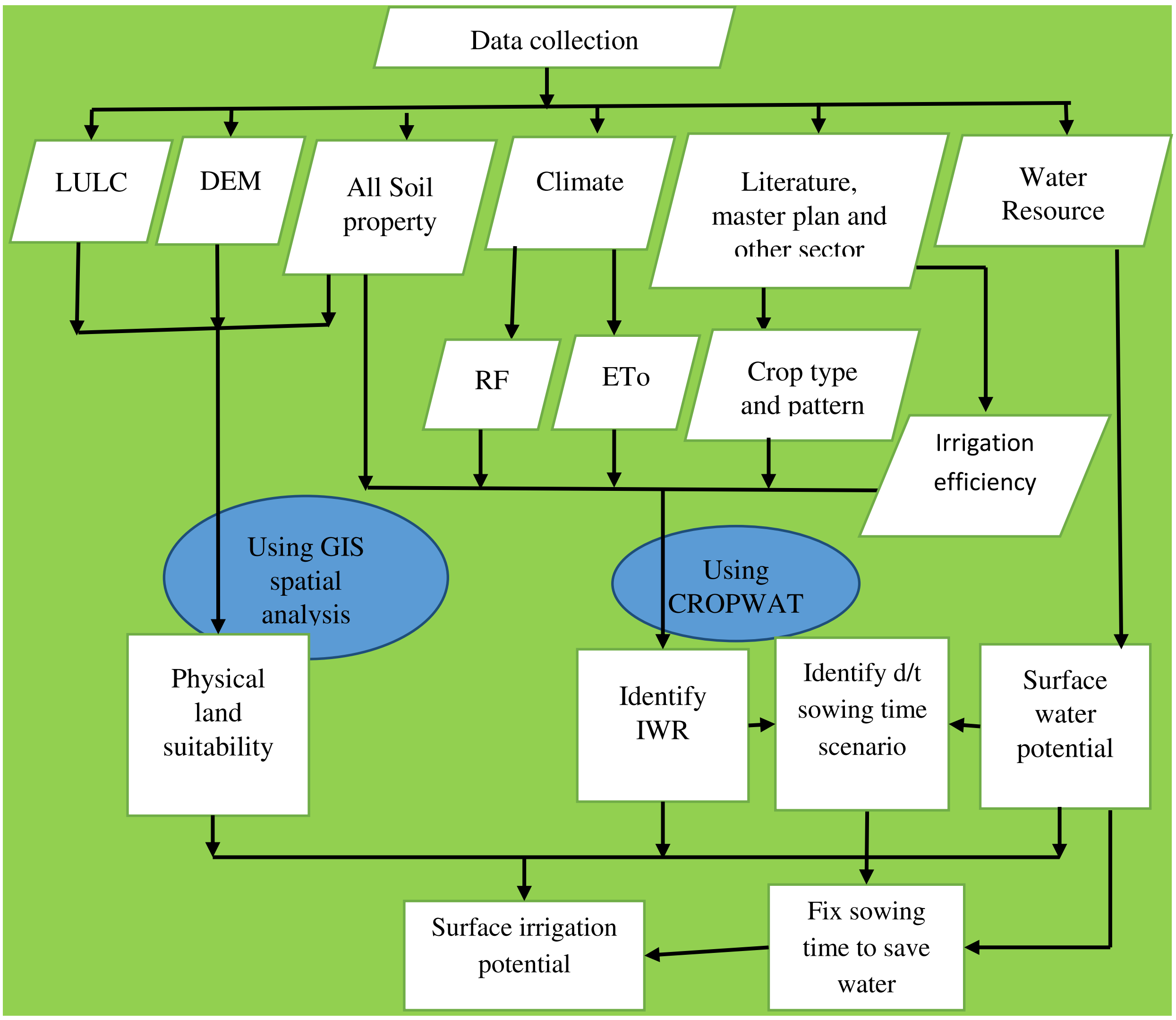

Figure 4: Methodological flow chart of the study.

Source: Edmealem and Gashaw, (2021) Assessment of Surface Irrigation Potential Availability using GIS in Gilgel Abbay Catchment; Ethiopia.

RESULTS AND DISCUSSION

3.1. Irrigation Land Suitability analysis

The analysis results of surface irrigation suitability evaluation factors are presented as the following sections.

Slope suitability

Slope is one of the evaluation parameters in irrigation suitability analysis. Based on FAO land suitability classification there are four slope classes (S1, S2, S3 and N) in the watershed (Fig. 5). The slope map of the study area was derived from the digital elevation model in Arc- GIS and classified in to four classes for surface irrigation suitability, i.e., from 0-2% as highly suitable (S1), 2-5% as moderately suitable (S2), 5-8% as marginally suitable (S3) and >8% as not suitable (N).The slope suitability for irrigation is shown in figure 5.

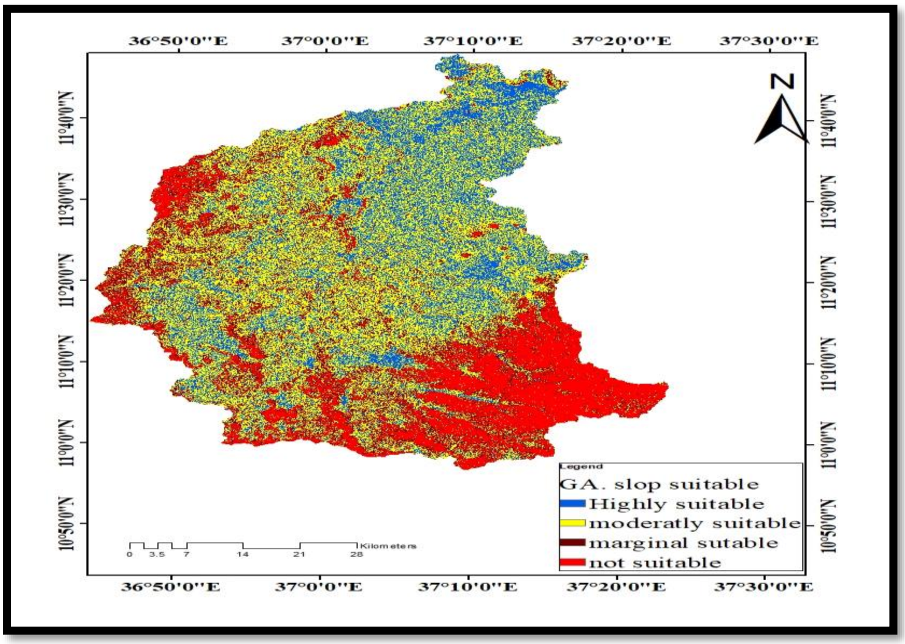

Figure 5: Slope suitability map of the study area/or surface irrigation

Table 6: Suitability classes of each slope category

Slope category (%)	Area coverage		Suitability
	ha	%	
0-2	94800	24.69	S1
2-5	154300	40.18	S2

5-8	58200	15.16	S3
>8	76600	19.95	N

Source: Edmealem T. and Gashaw S. (2018) assessment of surface water and cultivatable land resources Potential for surface irrigation in gilgel abbay catchment.

According to the slope classification result, the land having slope range below 2 % was classified as highly suitable while the slope range > 8% categorized as unsuitable class for surface irrigation. The suitability result indicates that 24.69% of the land was highly suitable, 40.18 % moderately suitable, 15.16% marginally suitable and only 19.95% was not suitable class for surface irrigation development.

Thus, 80.05% of the watershed range is from highly to marginally suitable for surface irrigation development in the Gilgel Abbay watershed. The area coverage of each slope suitability class and slope suitability map of the study area for surface irrigation are presented in the table 6 and figure 5.

Suitability of Soil

The land suitability of the watershed with regard to soil has been established by evaluating the soil suitability parameters; soil texture, depth, type, drainage and soil chemical property suitability through overlay analysis.

Soil type suitability

Soil type was taken as one input to develop irrigation suitability map for the catchment and woreda's administration. It was found that the major soil groups identified in the study area were Haplic Luvisols, Haplic Alisols, Eutric Vertisols, Chromic Luvisols, and Lithic Leptosols table 7.

Table 7: Suitability of soil type with their area coverage

Soil Type category(major group)	Area coverage		Suitability
	ha	%	
Haplic Luvisols	194,800	50.73	S1
Haplic Alisols	75,000.313	19.54	N
Eutric Vertisols,	38,800.361	10.11	S3
Chromic Luvisols	45,000.032	11.72	S2
Lithic Leptosols	30,200.6872	7.88	N

Source: Edmealem T. and Gashaw S. (2018) assessment of surface water and cultivatable land resources Potential for surface irrigation in gilgel abbay catchment.

Soil types of the study area was generally classified into four irrigation suitability classes based on soil suitability, such as S1 (highly suitable), S2 (moderately suitable), S3 (marginal suitability) and N (not suitable) see figure 6.

Haplic Luvisols covering an area of 50.73% of the study area, which is 194800ha, was classified as highly suitable (S1) for surface irrigation. Haplic Luvisols are known to be good for irrigation. This major soil type is technically characterized by a surface accumulation of humus overlying an extensively leached layer that is nearly devoid of clay and iron-bearing minerals. The second soil type is Chromic Luvisols covering an area of 11.72% of the study area, which is 45000.032ha, was classified as moderately suitable (S2) for surface irrigation.

Eutric Vertisols, was another soil type which covers 38,800.361ha, equivalent to 10.11% of the land in the study area. According to FAO (2006), these soils are classified as marginal suitable for surface irrigation. The remaining 105201ha which cover 27.42% is Haplic Alisols and Lithic Leptosols of the area is grouped as not suitable on the in terms of soil type suitability analysis.

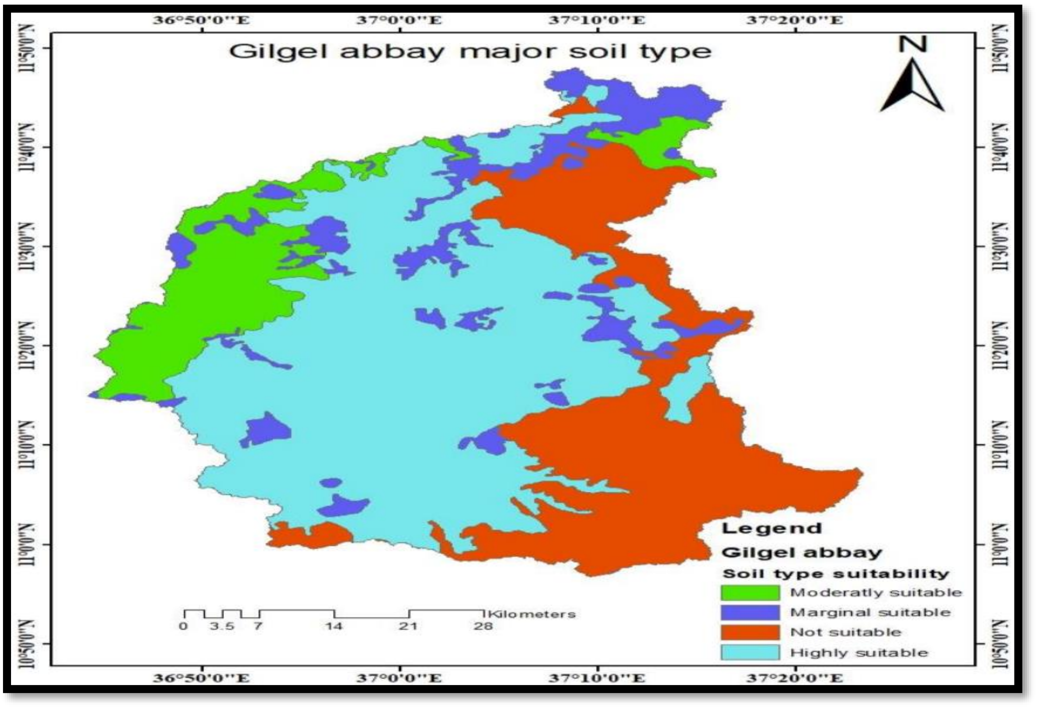

Figure 6: Soil type suitability map of the study area

Soil texture suitability

According to FAO guidelines for soil evaluation, the soil texture of the study area was evaluated and classified into clay (C), clay loam-clay (CL-C), loam-clay loam (L-CL), sandy loam (SL), and silty clay-clay (Sic-C). The soil textural classes of investigated soils in the current study area vary from clay to sandy loam. The results of texture class analysis reveal that the area was dominated by fine textured soils. The figure 7 elaborates the geographic distribution of the identified soil textural classes and their suitability in the study area.

Table 8: Soil texture classes of the study area.

Soil texture	Code	Area (ha)	Total area (%)
Clay	C	316200	82.34
Clay loam	CL	67800	17.66
Total		384000	100

Source: Edmealem T. and Gashaw S. (2018) assessment of surface water and cultivatable land resources Potential for surface irrigation in gilgel abbay catchment.

The soil textural classes and their area coverage's were shown in table 8 above. As described in the table 4.3: 82.34% of the total areas covered by the clay soil texture while about 17.66% area of the watershed were covered by CL.

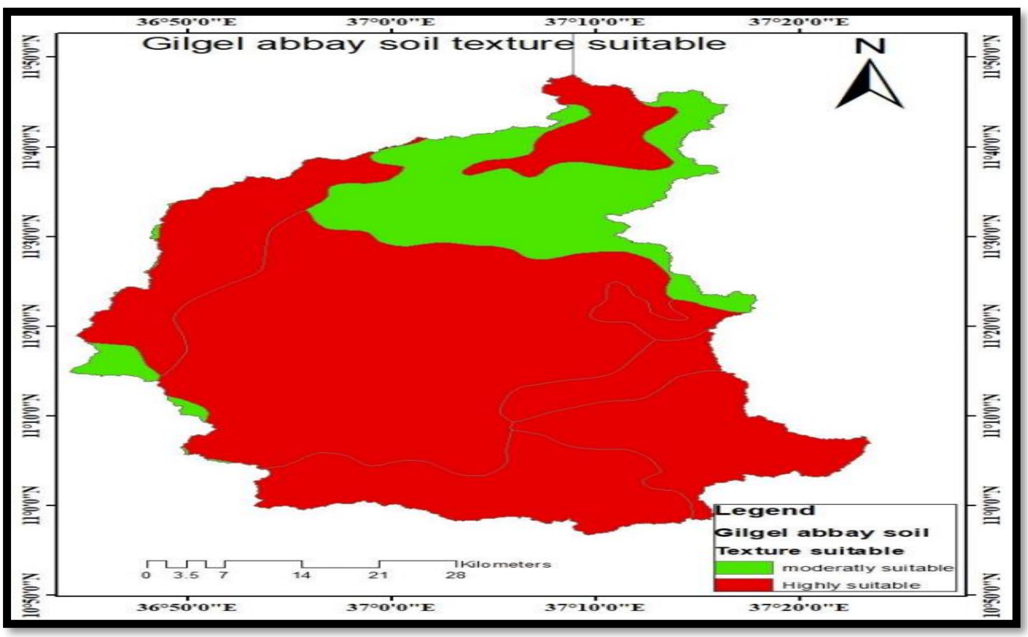

Figure 7: Soil texture suitability map of the watershed

The result of soil textural suitability analysis of the area revealed that 82.34% of soils in the area were under highly suitable for surface irrigation. Around 17.66% of the total area's soil was categorized under moderately suitable class for surface irrigation. The geographical location of these textural classes was described in texture suitability map have been presented in figure 7.

Soil depth suitability

Soil depth was considered as one of the major factors that determine the selection of land for surface irrigation potential in the study area. Soil depth determines the roots growth as well as presence of volume of water and air in the soil. The soil depth of the study area was divided into four: >150, 100-150, 50-100 and < 50 cm with a suitability class S1, S2, S3, N according to FAO (1991) respectively shown below in table 9 .The soil depth classes and their geographical location of the watershed was illustrated in figure 8.

Table 9: Soil depth suitability classes of the study area

Soil depth category (cm)	Area coverage		Suitability
	ha	%	
< 50	200	0.0521	N
50 – 100	200	0.0521	S3
100 – 150	225700	58.78	S2
>150	157900	41.12	S1

Source: Edmealem T. and Gashaw S. (2018) assessment of surface water and cultivatable land resources Potential for surface irrigation in gilgel abbay catchment.

The soil depth ranges from >150 cm, 100-150 cm, 50-100 and <50 cm covers an area of about 41.12%, 58.78%, 0.0521% and 0.0521% of the total land area respectively.

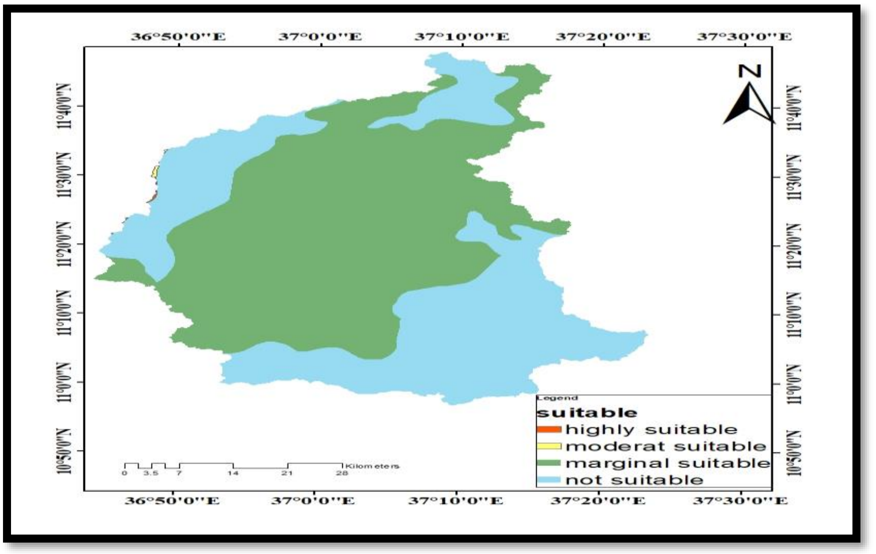

Figure 8 Soil depth suitability map of the watershed for surface irrigation

The soil depth suitability analysis result indicates that about 41.12% of the total area of the watershed was categorized under highly suitable, the area which is about 58.78% of the watershed was moderately suitable, 0.0521% of the total study area was marginally suitable and 0.0521% of the total study area is not suitable for surface irrigation development.

Generally, 99.95 % of the soil in the study area is in the range of highly to marginally suitable and the remaining 0.0521% of the area is grouped as not suitable on the in terms of soil depth suitability analysis. Suitability result of soil depth and their geographic locations in the catchment area is described in the figure 8.

Soil drainage and its suitability

FAO (1997) suggested that the soil drainage condition of a specific area to be classified into; well drained, moderately well drained, imperfectly drained, poorly drained and very poorly drained. Consequently, suitability map of soil drainage with in the study area was developed as it can be seen in the figure 9.

Table 10: Soil drainage suitability classes of the study area

Soil drainage category	Area coverage		Suitability
	ha	%	
well	321700	83.78	S1
Moderately well	24200	6.30	S2
Imperfectly	37700	9.82	S3
Poor drainage	400	0.104	N

Source: Edmealem T. and Gashaw S. (2018) assessment of surface water and cultivatable land resources Potential for surface irrigation in gilgel abbay catchment.

About 83.78% (321700ha) of the area have a well-drained soil, 6.30% (24200ha) of the area have a moderately well-drained soil, 9.82% (37700 ha) of the area have an imperfectly drained soil and 0.104% (400ha) of the soils were categorized under not drained class. The well drained soils are classified as highly suitable class, moderately well-drained soils are classified as moderately suitable class, and the imperfectly drained soils are categorized under marginal suitable and not drained soil class are not suitable for surface irrigation according to FAO guidelines. The figure 9 showed that the geographic location of drainage suitability of the area.

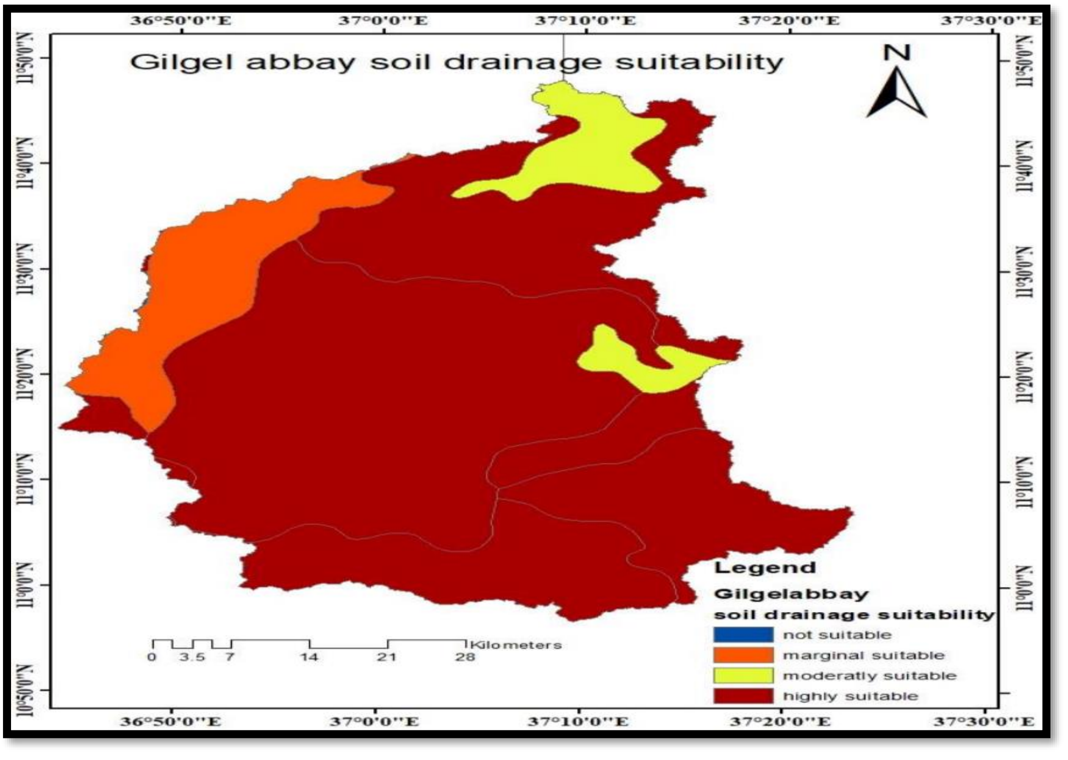

Figure 9: Soil drainage suitability map of the study area

Soil chemical properties analysis

A. Salinity and Alkalinity

The salinity of soil measured as saturated extract ranged from < 4 ds/m. This means that, at a time of irrigation there is a not need of leaching to reduce soluble salts from the farm land.

Majority of soil was found non-sodic, as carried on ESP value was less than < 10 %. Exchangeable Na were found in very low concentration in all mapping units and did not show significant variation. Since, the result of soil chemical property (Salinity and Alkalinity) suitability analysis of the area were under highly suitable for surface irrigation.

B. Soil reaction (pH)

Soil reaction value is an important indicator, which describes acidity and alkalinity of the soil and the availability and toxicity of macro and micronutrients. PH value of the soils in the study area ranges from 5.0 - 8.5. This indicates that the soils of the study area are in the range of highly suitable. Soils with the indicated pH values were preferred for most agricultural crops are shown below in table 11.

Table 11: factor rating suitability of chemical property of soil

Factors	Factor rating	Soil Suitability class
Salinity (EC in ds/m)	<4	Highly suitable
pH	5.0 - 8.5	Highly suitable
Alkalinity (ESP)	< 10	Highly suitable

Source: Edmealem T. and Gashaw S. (2018) assessment of surface water and cultivatable land resources Potential for surface irrigation in gilgel abbay catchment.

Overall soil suitability

The results of soil suitability in the weighted overlay analysis using revealed that about 25.03%, 63.29 %, 11.66 % and 0.022% of soils in the watershed were categorized under highly, moderately, marginally suitable and unsuitable classes respectively with the combined effect of the seven rasterized soil (drainage, depth, type, texture, Salinity, Alkalinity and pH) suitability classes. Table 10 shown below describes the geographic location how to analyze of the combined effect of soil suitability through weighted overlay analysis.

Table 12: Soil suitability in the weighted overlay analysis

S/N	Area coverage		Soil Suitability class
	ha	%	

1	96094.02	25.03	Highly suitable
2	242943	63.29	Moderately suitable
3	44763.23	11.66	Marginally suitable
4	85.90098	0.022	Not suitable
Total	384025.2	100	

Source: Edmealem T. and Gashaw S. (2018) assessment of surface water and cultivatable land resources Potential for surface irrigation in gilgel abbay catchment.

Generally, in the weighted overlay analysis 99.98 % of the soil of Gilgel abbay watershed was classified as highly to marginally suitable and 0.022 % of the total area was under not suitable classes. The areal distribution of the overall soil suitability map of the watershed is shown in figure 10.

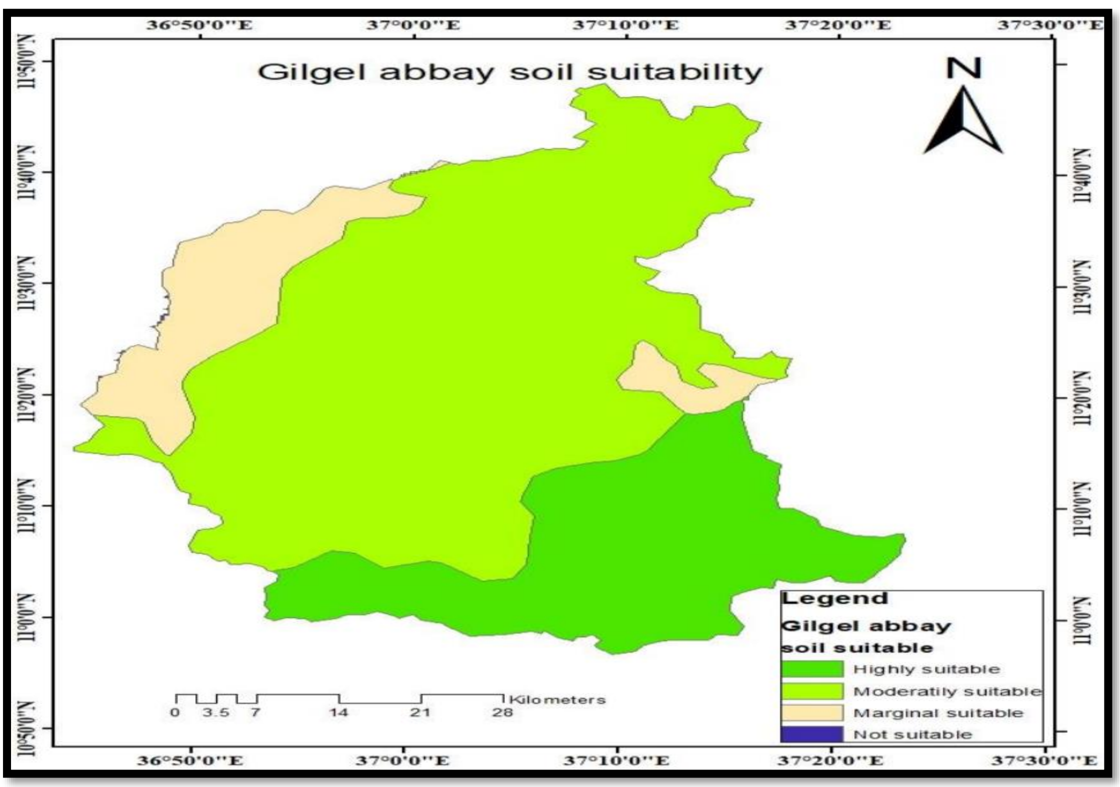

Figure 10: over all soil suitability distribution map for surface irrigation

Land use/land cover type and its suitability investigation

The five land use land cover types in the watershed included dominantly cultivated, grass land, shrub land, water and urban are available. As shown in Figure 10 cultivated land is the greatest share of land use land cover from all the land classes, which covers an area of 93.5 % of the total area.

Cultivated land: Areas used for crop cultivation, both annuals and perennials. This land cover is dominant as to other land cover types in the watershed which covers 93.48% (358,994ha) of the total area and exists in all parts of the watershed.

Grass land: Land area covered by open grass used for grazing purpose or pasture, as well as bare lands that have little grass. This land unit is covers an area of about 0.05% (187.34 ha) of the total area and mostly found in the upper part of the study area.

Shrub land: An area dominated with shrubs, bushes, and small trees, mixed with some grasses. It mostly found in the North-eastern part of the study area. This land unit is the second dominant land cover in the watershed which covers 6.4% (24448 ha) of the total area of the watershed.

The remaining areas are water and urban which covers 0.018% (67.29ha) and 0.086 % (328.36 ha) of the total area of the watershed respectively.

Land use/Land cover suitability investigation

The land use/cover types such as cultivated and grass lands were classified as highly suitable for irrigation. It covers 93.53% (359,182ha) of the total area of the watershed. Moderately suitable class is shrub land. This land use/cover accounts 6.4% (24448 ha) of the area. Other land covers types such as water and urban land covers were categorized under not suitable for irrigation, it covers 0.103% (395.65ha) of the total size of the study area. The land use land cover of Gilgel abbay watershed are shown below in table 13.

Table 13: LULC suitability of Gilgel Abbay watersheds

LULC classify	Area coverage		
	ha	%	Suitability
Cultivated land	3,58994	93.48	S1
Grassland	187.34	0.049	S2
Shrub land	24448	6.37	S3
water land	67.3	0.018	N
urban	328.36	0.09	N

Source: Edmealem T. and Gashaw S. (2018) assessment of surface water and cultivatable land resources Potential for surface irrigation in gilgel abbay catchment.

Generally, in the land use land cover suitability investigation, 99.9% of the watershed is highly to moderately suitable and the remaining 0.1% of the total watershed is not suitable for surface irrigation development. The land use land cover suitability map are shown below in figure 11.

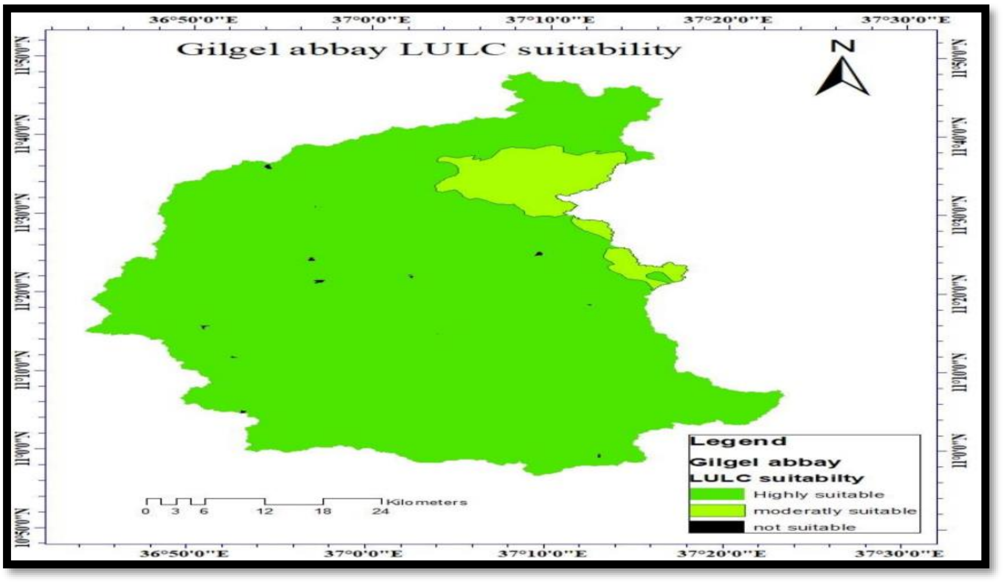

Figure 11: Land use land cover suitability map of Gilgel abbay watershed

Proximity to water

To identify irrigable land close to the water supply (rivers), straight-line (Euclidean) distance from watershed main river points was calculated. Spatial proximities to water sources were computed using spatial overlay of respective GIS layers. Influences of distance parameters on agricultural land suitability, table 14 were estimated using the clipped feature class was converted to raster using the conversion tool and reclassified in to suitability class based on its distance to the water source used "Reclassified tool "and shown in figure 12. Then, reclassified distance was used for weighted overlay analysis together with other factors.

Table 14: Proximity to water suitable for surface irrigation.

proximity to water	Area coverage		proximity Suitability class
	ha	%	
<1.5	358,994	93.48	S1
1.5 – 3	187.34	0.049	S2
3 – 5	24448	6.37	S3
>5	67.3	0.018	N

Source: Edmealem T. and Gashaw S. (2018)) assessment of surface water and cultivatable land resources Potential for surface irrigation in gilgel abbay catchment.

The result of Proximity to water suitable for surface irrigation indicate that, about 93.48%, 0.049 %, 6.37 % and 0.018 % area of the study was covered by highly suitable, moderately, marginally suitable and not suitable respectively. The Proximity to water suitable for surface irrigation suitability map of the watershed is shown in figure 12.

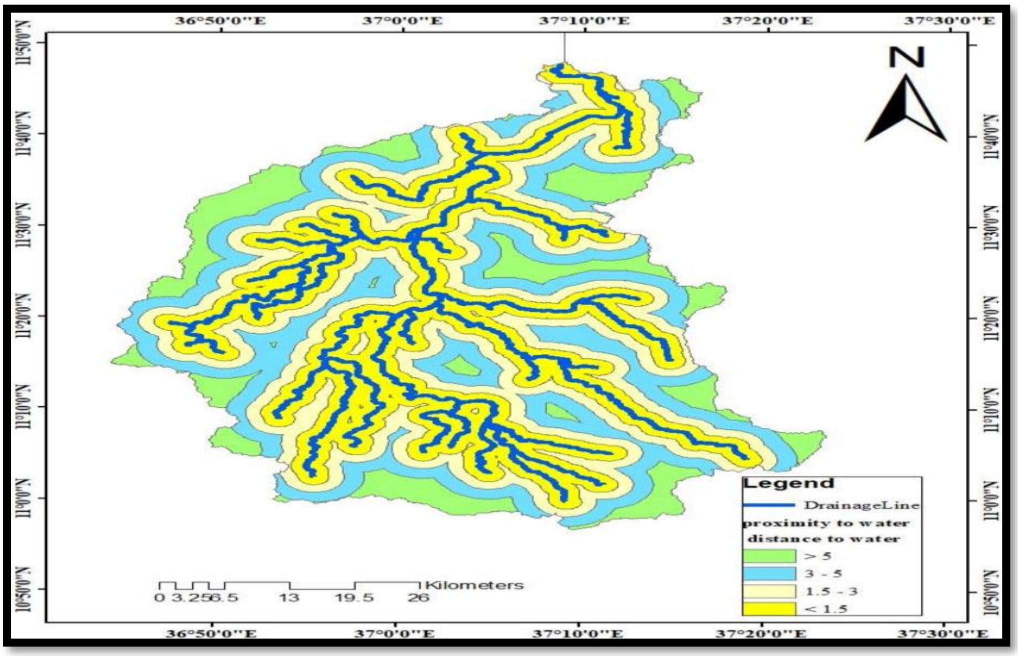

Figure 12: Proximity to water suitability map of Gilgel abbay watershed

3.2 Overall suitable sites for surface irrigation

Potential irrigable sites via the intended irrigation method were obtained using irrigation suitability analysis model developed on Arc GIS 10.2. The suitability model involved weighting of values of data sets such as soil, slope, land use/land cover and proximity suitability. Rasterized and reclassified suitability map of each parameter were used as input for the model. As elaborated below potentially suitable sites for surface irrigation development in the woreda's administration were identified with their area coverage and geographic location.

The three suitability parameters (Slope suitability, soil suitability, land use/land cover suitability and proximity suitability) used to identify potentially irrigable sites in the woreda's administration were used as the input for the developed irrigation suitability model to identify the most suitable and unsuitable sites for surface irrigation development.

In the irrigation suitability model, evaluation scale of 1 to 4 by 1 was used. 1 represents highly suitable class, 2 moderately suitable class, 3 marginally suitable class and 4 represents unsuitable classes. In the weighted overlay analysis high weight (% of influence) was given for slope, since it is the determinant factor in the evaluation of the given area for surface irrigation development.

Result of weighted overlay analysis of irrigation suitability model was presented in table 15 and figure 13 as shown below.

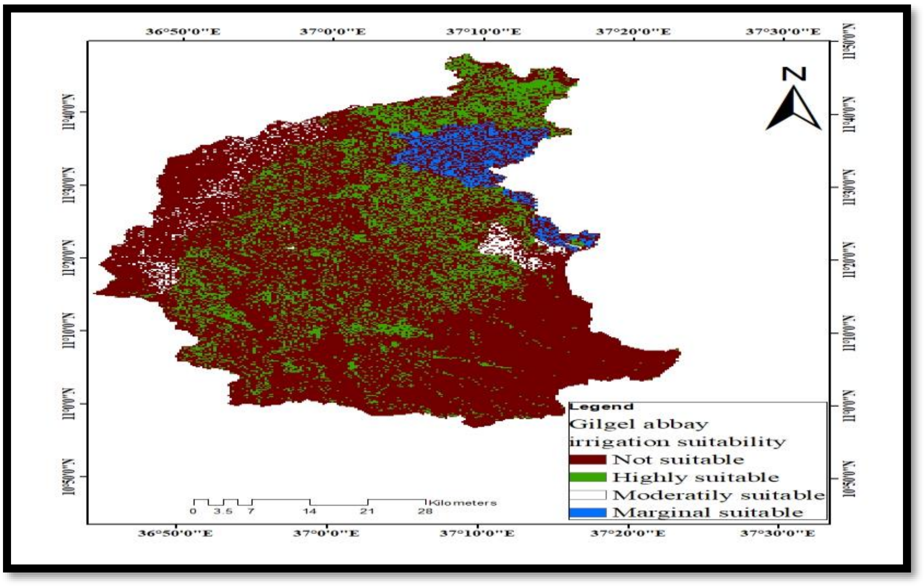

Figure 13: Map of suitable sites for surface irrigation

Generally, the result of suitability analysis through weighted overlay of the rasterized maps of the land suitability parameters revealed that about 22.59% (86,747.19 ha) of lands in the study area were in the range of highly to marginally suitable classes and the area categorized under non suitable class was about 77.41% (297,252.4 ha) which was presented in table 15.

Table 15: Overall suitable sites and their area coverage in the catchment.

No	Potentially suitable class	Area coverage	
		ha	%
1	Highly suitable	68806.38	17.91835
2	Moderately suitable	6322.564	1.646503
3	Marginally suitable	11618.25	3.025589
4	Not suitable	297252.4	77.40956
Total		383999.6	100

Source: Edmealem T. and Gashaw S. (2018) assessment of surface water and cultivatable land resources Potential for surface irrigation in gilgel abbay catchment.

Gillgel abbay watershed woreda's land suitability for surface irrigation.

In the study, a suitable site of the area in each woredas administration was identified and due to area coverage varying one to the other. Accordingly, the highest suitable area was identified in Mecha woreda while Yilmanedensa woreda has the least suitable area in the catchment, because Mecha woreda cover large area in the catchment than the other. Area coverage of irrigation land suitability in each woredas administration was presented in table 16.

Table 16: Overall suitable sites in each woredas administration

No.	woreda's name	Suitable class	Suitability rate	Area	
				ha	%
1	Mecha	Highly suitable	S1	25870	20.2
		Moderately suitable	S2	2934.2	2.29
		marginal suitable	S3	6553.5	5.12
		Not suitable	N	92582	72.4
		sub total		127940	100
2	South-Achefer	Highly suitable	S1	10535	15.8
		Moderately suitable	S2	1274.2	1.91
		Not suitable	N	55030	82.3
		sub total		66839	100
3	Dangla	Highly suitable	S1	7766.2	18.4
		Moderately suitable	S2	1226	2.91
		Not suitable	N	33175	78.7
		sub total		42168	100
4	Sekela	Highly suitable	S1	1419	3.51
		Not suitable	N	39014	96.5
		sub total		40433	100
5	Fagtal akuma	Highly suitable	S1	5661.4	15.1
		Not suitable	N	31859	84.9
		sub total		37521	100
6	North Achefer	Highly suitable	S1	7774.6	25.8

		Moderately suitable	S2	1066.3	3.54
		marginal suitable	S3	5.3677	0.02
		Not suitable	N	21295	70.7
		sub total		30142	100
7	Bahir-Dar zuria	Highly suitable	S1	8892	33.5
		Moderately suitable	S2	4917.4	18.5
		Not suitable	N	12720	47.9
		sub total		26529	100
8	Banja	Highly suitable	S1	533.83	6.29
		Not suitable	N	7948.5	93.7
		sub total		8482.4	100
9	Quarit	Highly suitable	S1	5.3677	0.5
		Not suitable	N	1065.8	99.5
		sub total		1071.2	100
10	Yilmanedensa	Highly suitable	S1	5.3677	0.8
		Not suitable	N	669.46	99.2
		sub total		674.83	100

Source: Edmealem T. and Gashaw S. (2018)) assessment of surface water and cultivatable land resources Potential for surface irrigation in gilgel abbay catchment.

The overall suitability map of woreda administration are shown below in figure 14

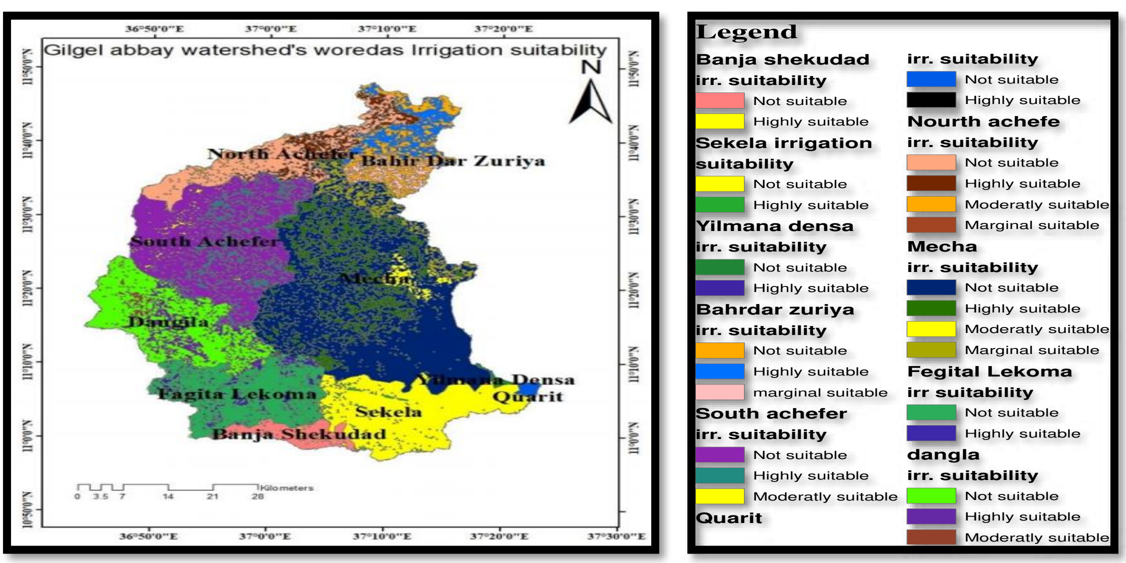

Figure 14: over all suitability map for Woreda’s administration

3.3. Water availability

The surface water potential of major streams situated in the basin is considered. Here the estimation is based to perennial rivers (Q100 = 100%) whose flow records are available. The availability of water will always be of prime importance, before any decisions can be made on the best use to which it can be applied. The hydrological analysis of water resource will always be the first step in developing it.

The long term measured flow data of Gilgel Abbay River was obtained from Hydrology Department of the Ministry of Water Resources. The flow data was used to assess water resources potential of the gauged and ungauged sites for irrigation purpose. Average annual monthly stream flow, maximum and minimum flow was evaluated. But effective irrigable area was calculated based on minimum stream flow. The following table 17 and 18 shown that mean, max. and min. annual monthly flow before and after 25% released for ecological purpose respectively.

Table 17: Mean, Max. and Min. annual monthly flow before 25% released

month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
min (m3/s)	6.1	4.26	2.56	2.27	2.27	3.99	29.3	142	94.5	25.5	15.6	8.77	28.0936
max (m3/s)	61	41.1	69	67.5	278	473	1409	1436	919	674	230	139	483.055
mean (m3/s)	18	13.1	11.2	11.1	25.5	111	336	434.8	325	142	52.6	29.1	125.747

Source: Edmealem T. and Gashaw S. (2018) assessment of surface water and cultivatable land resources Potential for surface irrigation in gilgel abbay catchment.

The annual average min, max and mean flow was recorded 28.094m^3/s, 483.055 m^3/s and 125.75m^3/s respectively.

Table 18: Mean, max, and min annual monthly flow after 25% released

month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
min (m3/s)	4.575	3.2	1.92	1.7	1.7	2.99	22	106.5	70.9	19.1	11.7	6.578	21.0702
max (m3/s)	45.75	30.8	51.8	50.6	209	355	1057	1077	689	506	172.5	104.3	362.291
mean (m3/s)	13.5	9.82	8.38	8.33	19.1	83.3	252	326.1	244	107	39.45	21.83	94.31

Source: Edmealem T. and Gashaw S. (2018) assessment of surface water and cultivatable land resources Potential for surface irrigation in gilgel abbay catchment. Maximum and minimum flow were generate in August and April respectively.

3.4. Calculation of Crop water requirement

Selected crops to be grown in the area were calculated assuming double cropping practice in the area. The first one was assumed using rainfall (rain fed cultivation). After crops of the first phase cultivation were harvested; land preparation was overtaken and the second phase cultivation was preceded using the intended irrigation method. According to crop calendar of the area the first phase land preparation was started at the month of April and crops were harvested starting from first-November till February. Therefore, land preparation for the second phase-irrigated cultivation was started at early of January and harvesting period varies from early April to end of May based on the selected crops. The estimated crop water requirement of selected crops is shown below in table 19.

Table 19: Monthly crop water requirement of selected crops in mm

Month	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
Type of crops													
banana	31.7	40.6	46	57	66.9	75.3	71.3	70.4	83.3	93	96.9	11.8	744.2
barley	21.6	79.3	105.3	97.5	9.9	0	0	0	0	0	0	0	313.6
wheat	27	63.2	105	101	13.2	0	0	0	0	0	0	0	309.4
tomato	38	58.7	99.4	124.3	108	8.2	0	0	0	0	0	0	436.6
potato	31.7	63.8	105.2	120.6	55.5	0	0	0	0	0	0	0	376.8
Sugarcane	43.3	42.1	82.2	127.1	129.3	126.7	106.5	94.8	100	103.3	95.3	75.9	1127
cabbage	44.4	58.4	79	109.3	113	79.5	0	0	0	0	0	0	483.6
cotton	22.1	40.8	90.3	129	129.4	104.2	44.1	0	0	0	0	0	559.9
maize	19.1	61.8	109.4	114.1	24.1	0	0	0	0	0	0	0	328.5
sorghum	19.1	53.4	91	99.2	29	0	0	0	0	0	0	0	291.7
Total	298	562.1	912.8	1079	678.3	393.9	222	165	183	196	192	87.7	4971

Source: Edmealem T. and Gashaw S. (2018) assessment of surface water and cultivatable land resources Potential for surface irrigation in Gilgel Abbay catchment.

Different crops have different crop water requirement within the study area. Crop water requirement of all crops such as, banana, sugarcane, cabbage, potato, tomato, maize, cotton, barely, wheat and maize, was presented for each month in table 19. From all crops, sugarcane has needed the highest crop water requirement which recorded 1127 mm/growing period and Sorghum has the minimum crop water requirement in the study area was evaluated 291.7 mm/growing period.

3.5. Gross irrigation water demand

Irrigation water requirement of each the selected crops were calculated using CROPWAT.8 software. For the calculation of ETc/CWR, data from Dangila meteorological station was used. As indicated in appendix table, different percentage of area coverage was adopted for each crop based on the assumed benefits the farmers will obtain from them.

To evaluate the water resource and water requirement in the catchment, compute gross irrigation requirement. During evaluation of the water resource in the catchment, 25% of the mean monthly stream flow was maintained for downstream ecological balance. Therefore, the overall irrigation efficiency was calculated using the recommended formula by FAO irrigation and drainage paper no.24 and it was reduced from 100 % to 54 %. The estimated irrigation water demand for each crop is shown below in table 20.

Table 20: Grosse irrigation water demand for each crop in m3/s

	month	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	average
No	types of crop													
1	banana	1.52	1.95	2.2	2.73	3.21	3.6	3.42	3.4	3.99	4.46	4.6	0.6	2.9724
2	barley	1.04	3.8	5.05	4.67	0.47	0	0	0	0	0	0	0	1.2525
3	tomato	1.82	2.81	4.76	5.96	5.18	0.4	0	0	0	0	0	0	1.7438
4	potato	1.52	3.06	5.04	5.78	2.66	0	0	0	0	0	0	0	1.505
5	sugarcan	2.08	2.02	3.94	6.09	6.2	6.1	5.1	4.5	4.79	4.95	4.6	3.6	4.4993
6	cabbage	2.13	2.8	3.79	5.24	5.42	3.8	0	0	0	0	0	0	1.9315
7	cotton	1.06	1.96	4.33	6.18	6.2	5	2.11	0	0	0	0	0	2.2363
8	maize	0.92	2.96	5.24	5.47	1.16	0	0	0	0	0	0	0	1.312
9	suorghum	0.92	2.56	4.36	4.75	1.39	0	0	0	0	0	0	0	1.1651
10	wheat	1.29	3.03	5.03	4.84	0.63	0	0	0	0	0	0	0	1.2358

Source: Edmealem T. and Gashaw S. (2018) assessment of surface water and cultivatable land resources Potential for surface irrigation in gilgel abbay catchment.

From selected dominant crops maximum and minimum gross irrigation water demand of sugarcane and sorghum were recorded 53.99m^3/s and 13.98m^3/s or 5.38Mm^3 and 2.38Mm^3 throughout the growing period due to growth period length and crop water requirement respectively. Total irrigation water demand for the catchment 579.09Mm^3 of water was maintained to irrigate the whole irrigable area of 86961.24ha of land on these specified crops.

3.6. Physical irrigation potential on Gilgel Abbay watershed

The gross monthly irrigation requirement of the selected crops (tomato, potato, sugarcane, cabbage, cotton, maize, wheat, barley, banana, and sorghum) and available min. monthly flows of the catchment. The analysis done by the following procedure with the same area (8696.124ha) for each crops and sowing time is December. The estimated irrigable area for each month are shown below in table 21.

Table 21: Based on the Minimum available water, the effective irrigable area (ha) can be estimated in each month and at different scenario

	Month	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
	Flow)m3/s)	4.5909	3.1982	1.921	1.701	1.701	2.991	21.978	106.49	70.875	19.14	11.67	6.577	252.8
No.	Types of crop													
1	banana	18394	10005	5303	3790	3229	5045	39149	192116	108063	26136	15296	70786	5E+05
2	barley	26995	5122.2	2317	2216	0	0	0	0	0	0	0	0	36649
3	tomato	15344	9933.3	5866	4691	5399	0	0	0	0	0	0	0	41234
4	potato	18394	9139.2	5543	4835	0	0	0	0	0	0	0	0	37911
5	sugarcan	13466	13850	7093	4588	4510	4602	5475	6150.7	5830.8	5645	6118.4	7682	85011
6	cabbage	13133	9984.3	7381	5335	5160	0	0	0	0	0	0	0	40992
7	cotton	26384	14291	6457	4520	4506	5596	0	0	0	0	0	0	61754
8	maize	30528	9435	5330	5110	0	0	0	0	0	0	0	0	50403
9	suorghum	30528	10919	6408	5878	0	0	0	0	0	0	0	0	53733
10	wheat	21596	6427.1	2323	2139	0	0	0	0	0	0	0	0	32485
11	total	193165	92679	51698	40962	22804	15243	44624	198267	113894	31781	21415	78468	

Source: Edmealem T. and Gashaw S. (2018) assessment of surface water and cultivatable land resources Potential for surface irrigation in Gilgel Abbay catchment.

According to FAO, 1997 Physical surface irrigation potential for surface irrigation was obtained by comparing irrigation water requirement in identified irrigable land and the available stream flow of watershed. From the total stream flow, 25% of the available stream flow on watershed was released to the downstream for ecological purpose. In the whole growing season from January-May irrigation water demand was greater than the available stream flow. Minimum monthly stream flow and grosses irrigation water requirement of selected crop such as, tomato, potato, sugarcane, cabbage, cotton, maize, wheat, barley, banana, and sorghum were present in the table 21 above.

Table 22: Effective irrigable area at each month for each crop

No.	Types of crd	area	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
1	banaa	irrigated	18394	10005	5303	3790.3	3229	5045	39149	192116	108063	26136	15296	70786
		non	-9698	-1309	3393	4905.8	5467	3651	-30453	-2E+05	-99367	-17440	-6600	-62090
2	barley	irrigated	26995	5122	2317	2215.9								
		non	-18299	3574	6379	6480.3	8696							
3	cabge	irrigated	13133	9984	7381	5334.7	5160							
		non	-4436	-1288	1315	3361.4	3536	8696						
4	cotton	irrigated	26384	14291	6457	4520	4506							
		non	-17688	-5595	2239	4176.1	4190							
5	maize	irrigated	30528	9435	5330	5110.3								
		non	-21832	-739	3366	3585.8	8696							
6	potato	irrigated	18394	9139	5543	4834.9								
		non	-9698	-443	3154	3861.3	8696							
7	sugercane	irrigated	13466	13850	7093	4587.6	4510	4602	5475	6150.7	5830.8	5644.6	6118.4	7682
		non	-4770	-5154	1603	4108.5	4187	4094	3221	2545.4	2865.3	3051.6	2577.7	1014
8	suorghum	irrigated	30528	10919	6408	5877.9								
		non	-21832	-2223	2289	2818.3								
9	tomato	irrigated	15344	9933	5866	4690.9	5399							
		non	-6648	-1237	2830	4005.2	3297							
10	wheat	irrigated	21596	6427	2323	2139.1								
		non	-12900	2269	6373	6557.1								

Source: Edmealem T. and Gashaw S. (2018) assessment of surface water and cultivatable land resources Potential for surface irrigation in gilgel abbay catchment.

Negative non irrigated area show that excess amount of water available than the land potential whereas the positive non irrigated area is excess land is available than stream minimum water (Due to lack of available water, most of irrigable area is not irrigated and is not covered by agricultural production). By subtracting irrigated land from total land potential I have got non irrigated land area.

As shown in table 22, effective irrigable area of each month is vary from month to month due to variation of minimum flow. For example, as shown in table 22, the maximum irrigable area within the minimum flow for each month (Dec, Jan, Feb, Mar and Apr) were 26994.63ha, 5122.21 ha, 2316.77 ha, 2215.86 ha, respectively. The actual average irrigable area of land is 9162.4ha was irrigated within the total minim flow of 13.11m3/s and gross irrigation water covered is 15.03 m3/s by the barely crop. The minimum flow of river can be irrigate 5747.1ha above the land potential. The remaining effective irrigable area is covere by other crops which is calculated on the same procedure in Appendix.

Storage requirement in irrigable area at different scenario

Available surface water potential of Gilgel abbay River is estimated minimum or low monthly flow. In order to obtain the reliable low flow, flow duration curve (FDC) is developed and different sowing time was estimated.

Irrigation water demand for common crop during the growing season was estimated by using the available climate, soil and cropping pattern data. Irrigation water demand over the entire irrigable area was calculated and compared with the available flow table 23. Most of the time in Ethiopia the sowing time starting in November. But the scenario include four month (November, December, January and February) by taken from two season (winter and spring).

Table 23: Irrigation water demand and irrigable area at different scenario

Types of crops	area cover (ha)	Possible irrigated area at different scenario							
		November		December		January		February	
		storage requirement	area	storage requirement	area	storage requirement	area	storage requirement	Area
		Mm^3	ha	Mm^3	ha	Mm^3	ha	Mm^3	Ha
banana	8696.124	912.97	33624.67	39.38	41442.75	50.44	35795.06	57.15	30207.7
Barley	8696.124	360.64	6279.171	26.83	11694.46	45.59	6201.49	47.08	5951.219
Cabbage	8696.124	577.67	5019.026	47.21	12464.12	70.69	5307.306	80.38	2009.742
Cotton	8696.124	673.33	5986.189	39.38	6552.713	35.28	6375.626	40	3046.199
Maize	8696.124	372.07	11880.23	53.79	28452.84	35.78	12076.68	38.01	6853.823
Potato	8696.124	432.45	5978.957	55.16	5307.151	51.93	6061.604	57.77	5926.395
Sugarcane	8696.124	1402.9	27380.6	27.45	15618.12	40.37	27914.21	45.72	26618.6
Sorghum	8696.124	332.81	10530.66	23.73	10037.72	34.54	10745.05	37.14	11247.7
Tomato	8696.124	505.74	4679.135	23.73	10088.62	60.62	4773.054	68.82	4461.207

Wheat	8696.124	356.91	9469.868	33.54	9770.474	30.19	9766.9	34.16	9608.268
Total	86961.24	5,927.5	120,828.5	370.2	151,429	455.4	125,017	506.2	105,930.8

Source: Edmealem T. and Gashaw S. (2018) assessment of surface water and cultivatable land resources Potential for surface irrigation in gilgel abbay catchment.

The result shows that total irrigation water demand is 5927.5Mm^3, 370.2 Mm^3, 455.4 Mm^3 and 506.2 Mm^3 for November, December, January and February sowing time scenario respectively to irrigate 86961.24ha of irrigable land. But, due to lack of available water the area is irrigated only 37169.61ha with in the total minimum flow 252.83m^3/s. Accordingly, to irrigate from the whole irrigable area of 34950ha of land is require 144.76m^3/s of irrigation water must be store throughout the growing period within this scenario. Due to this reason storage structure must be recommended with in the study area. Generally, monthly effective irrigable area at different scenario was calculated.

CONCLUSIONS

By developing irrigation infrastructure we will increase agricultural productivity, improve food security levels,s and develop the Ethiopian economy. This can be achieved by assessing available land and water resources potential for irrigation with select the dominant crops in the study area. The factors which were considered for evaluation of the land for surface irrigation of the Gilgel Abbay catchment are the slope of the land, soil depth, soil texture, soil type, soil drainage, soil stoniness, soil chemical property, land use land cover and water resources such as drainage nature and climate. These factors were also used for the suitability of ten dominant crops under the study area in different sowing time scenarios. The study results indicated that about 99.9%, 99.98 %, 80.05%, and 99.98% of the study area is in the range of highly suitable to marginally suitable for surface irrigation development based on the LULC, soil, slope, and proximity to water of the river basin, respectively. The total land under the study area which is suitable for surface irrigation is 22.59% (86,747.19 ha) were in the range of high to marginally suitable classes and the area categorized under non-suitable class was about 77.41% (297,252.4 ha) of the Gilgel Abbay catchment. The water resources availability in the study area is annual average min, max, and mean flow was recorded 28.094m^3/s, 483.055 m^3/s, and 125.75m^3/s respectively. The sowing time scenario for the dominant selected ten crops results shows that total irrigation water demand is 5,927.5Mm^3, 370.2 Mm3, 455.4 Mm^3, and 506.2 Mm^3 for November, December, January, and February sowing time scenario respectively to irrigate 86961.24ha of physical irrigable land. But, due to lack of available water, the area is irrigated only 37,169.61ha within a total minimum flow of 252.83m^3/s. Accordingly, to irrigate from the whole irrigable area of 34,950ha of land is require 144.76m^3/s of irrigation water must be store throughout the growing period within this scenario. Due to this reason storage structure must be recommended within the study area and use December sowing time.

Recommendation

- This study was limited with soil texture, soil depth and drainage to assess Land suitability for surface irrigation. Since, other factors may have its own influence to characterize the suitability of land for surface irrigation. Therefore, further research which will be incorporate additional factors such as soil chemical characteristics (except alkalinity, acidity and pH) electric conductivity with the aid of laboratory analysis to assess land suitability over the study area.
- Suitability analysis of land for irrigation was done by considering only surface irrigation which covers an area of about 86961.124ha. Furth investigate is recommended to increase suitability of land for irrigation by considering drip and sprinkler irrigation method.
- Since irrigation water demand is greater than the available stream flow, construction of storage structures is recommended to fully develop the identified irrigation potential in the study area
- Suitability of the land for surface irrigation was examined on the current development need. Further investigate should include future scenarios

- ❖ In the current study only ten crops were evaluated for surface irrigation development other crops may be evaluated for the area to increase opportunity of production.

Data Availability statement

All the required data are available in this article.

Conflict of interest

All the authors declare that they have no conflicts of interest.

Authors' contribution

All authors contribute to the research starting from proposal drafting to documentation**.**

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