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ORIGINAL PAPER

GIS-based land suitability assessment for surface irrigation: a case of Gilgel Gibe watershed, Jimma Zone, Ethiopia

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Abstract
Systematic assessment of available water and potential land surface suitable for irrigation at watershed level is essential for the planning and decision-making of new irrigation development projects. Hence, the intended aim of this research is to assess the land suitable for surface irrigation and available surface water in Gilgel Gibe watershed using Geographical Information System (GIS) and Remote Sensing (RS) technique. The surface water availability was evaluated by developing flow duration curve (FDC) and analyzing 90% available flow of Gilgel Gibe River. The land surface suitability was determined through GIS-based multi-criteria evaluation (MCE) technique, which considers the interaction of major land suitability factors such as slope, river proximity, soil type, and land use land cover. The factors were weighted using a pair-wise comparison matrix to evaluate the importance of one factor over the other, for physical land suitability. The result indicated that about 2.64, 14.61, and 58.27% of the catchment were found to be highly, moderately, and marginally suitable, respectively, and the remaining 24.48% was found to be not suitable in terms of physical land suitability. In terms of water availability, the flow duration curve (FDC) result indicated that the 90% available flow throughout the year of Gigel Gibe River is 9.13 m^3/s. Hence, in the month of December, the river has a capacity of irrigating only 5.79% of total irrigable land, while in the months of May to September, the river has a capacity of irrigating the whole irrigable land. The low flow of the river has a potential of irrigating large area in wet season and less area in dry season. Hence, water storage structures are needed to irrigate the whole potential irrigable land during dry season.

Keywords Gilgel Gibe · GIS · Irrigation · Land suitability · Multi-criteria evaluation · Watershed

Introduction

Ethiopia is blessed with ample water resource within 12 river basins, in which 9 are wet and the 3 are dry river basins (Awulachew et al. 2007 and Nigussie et al. 2019). The country is naturally endowed with water resource that could satisfy its requirements for domestic, irrigation, and hydropower, if sufficient financial resources were made available for storage infrastructure. The total annual surface runoff is estimated to be about 125 billion m^3 (Awulachew et al. 2010). Despite the abundance of the water resource, the distribution and availability of water is spatially and temporally varied. The Western and South-Western parts of the country possess about 80–90% of all surface water resource whereas Central and Eastern parts possess the remaining 10–20% of the countries' surface water resource. The flow is also highly varied seasonally, that is maximum in wet season and minimum in dry season (MoWR, 2002).

Agriculture is the backbone of Ethiopian economy. It employs about 85% of the population and contributes approximately 50% of the gross domestic product (GDP) (Haile and Kassa, 2015). But, the agricultural production of the country is largely based on rain-fed agriculture which enables the farmers to produce crops only once in a year as the rain is seasonally variable in the country and is available only for a single cropping period. To produce crops more than once in a year, water storage structures are needed to store water for a dry season usage. But, due to lack of finance for construction of storage structures, skilled manpower for

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system installation and awareness among farmers the phenomenon is continued, and the suitable land for irrigation remains under-utilized (Awulachew et al. 2010).

The country level irrigation potential, which is estimated and presented by FAO (2005), is about 2.7 million ha of land. On the other hand, Awulachew et al. (2010) indicated that Ethiopia has 5.3 million ha of land suitable for irrigation. This magnitude of irrigation potential is estimated considering the available water and land resource, technology, and finance. Despite the irrigation potential of the country, only 5% of it is currently under irrigation development (Meja et al., 2020).

Production of crops more than once in a year, by introducing irrigation in Ethiopia, is basic strategy to alleviate poverty and hence to achieve food security of the country by overcoming the effect of rainfall variability and unreliability. According to Hagos et al. (2011), production of crops through irrigation generates an average income of approximately US$ 323/hectare (ha) under small holder-managed irrigation system compared to an average income of US$ 147/ha by rain-fed system. Hence, to meet this goal, the irrigation expansion needs to be supported by some decision support system in order to be more efficient and effective while using the land and water resource for irrigation. In this regard, GIS and Remote Sensing offer a convenient and powerful platform to integrate spatially complex attributes for performing land suitability analysis. The weighted overlay module of GIS and its approach for land suitability analysis prove to be useful method to generate and observe the net result of suitable land from different land suitability determining factors. These factors include topography (slope), distance from the rivers, soil type, and land use land cover (LULC) type. A melty-criteria evaluation approach combines these factors to form a single indexed output. Out of the different methods of combination of factors such as Multi-Attribute Utility Theory (MAUT), Weighted Sum Model (WSM), and Analytical Hierarchy Process (AHP) (Satty, 1977 and Miller et al. 1998), AHP is used for this analysis due to its wide application in water resource management (Worqlul et al. 2015).

The study area (Gilgel Gibe watershed) is a major tributary of Omo-Gibe river basin. On this watershed, a variety of researches have been done so far. For instance, Takala et al. (2016) studied about The Effects of Land Use Land Cover Change on Hydrological Process of Gilgel Gibe, Omo Gibe Basin, Ethiopia, and Demissie et al. (2013a, b) have investigated the Climate change impacts on the streamflow and simulated sediment flux to Gilgel Gibe I hydropower reservoir, Ethiopia. Ambelu et al. (2013) also did research on Hydrological and anthropogenic influence in the Gilgel Gibe I reservoir (Ethiopia) on macroinvertebrate assemblages. But no one has addressed the issue of irrigation potential assessment on this watershed so far, even though assessing the available resource is very crucial for the planers. Hence, the intended aim of study is to investigate, potentially suitable surface of land for irrigation and water availability for the identified irrigable land in Gilgel Gibe watershed.

Materials and methods

Description of the study area

The study area (Gigel Gibe catchment) is found in Jimma Zone, Oromia, South-Western part of Ethiopia (Figs. 1, 2, 3, and 4). It is about 260 km far from the capital city (Addis Ababa) to South-West direction. Geographically, it is located between 7° 19′ 07″ and 8° 12′ 09″ North latitude and 36° 31′ 42″ and 37° 25′ 16″ East longitude. For this research, the outlet of the catchment is considered to be Gilgel Gibe I Hydropower Reservoir with total catchment area of about 4200 km^2. The catchment is generally characterized by high relief variation, which ranges between about 1650 and 3360 m amsl. It is also characterized by wet climate, with an average annual rainfall of 1550 mm and average temperature of 19 °C. The seasonal rainfall distribution takes a uni-modal pattern with its maximum during summer and minimum during winter, influenced by inter-tropical convergence zone (ITCZ) (Demissie et al. 2013a, b).

Sources of data

The key factors considered evaluating the suitability of land for irrigation include biophysical features (such as climate, land use and land cover, soil proximity to the river, and slope) and socioeconomic factor (such as proximity to road and population density) (Worqlul et al. 2019). But, most researcher applied the biophysical factors for land suitability (Hailu and Shoeb, 2017; Mandal et al. 2018 and Kassaye et al. 2019). Hence, in this research, factors such as topography (slope) of the land, soil type, availability of water, proximity to the river, and the land use land cover type of the area are used for land suitability assessment. For the analysis, data such as meteorological data (min and max temperature, rainfall, wind speed, sunshine hour, and humidity) for the year (1990–2017) were collected from Ethiopia National Metrological Agency (ENMA). Historical river flow data (1990–2013), soil data, and digital elevation model (DEM) data were collected from Ethiopian Ministry of Water, Irrigation and Energy (MoWIE), and the land use land cover (LULC) map of 2018 was collected from Ethiopian Mapping Agency (EMA).

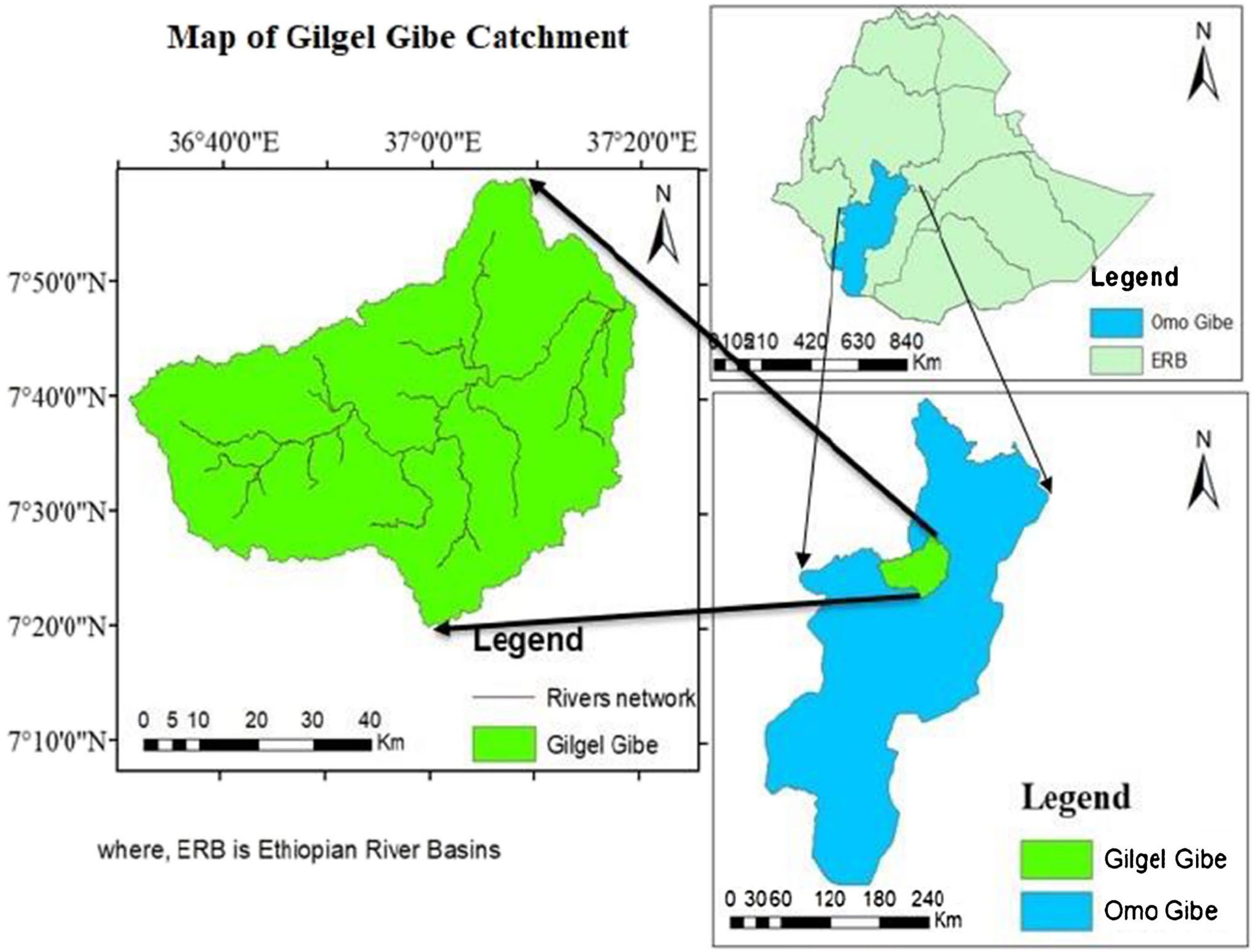
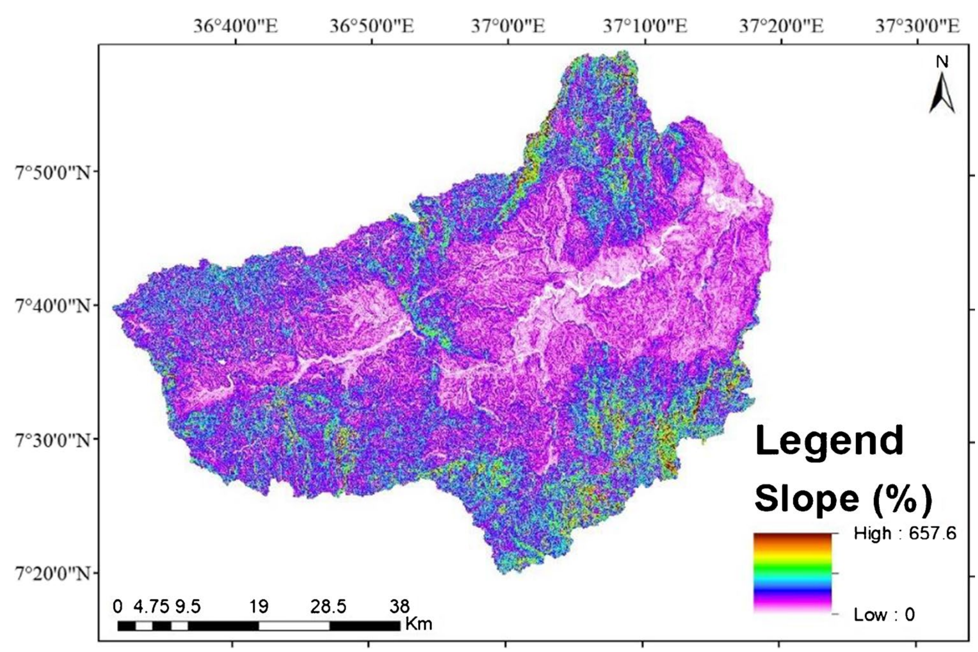


Fig. 1 Location map of the study area

Fig. 2 Slope map of the study area



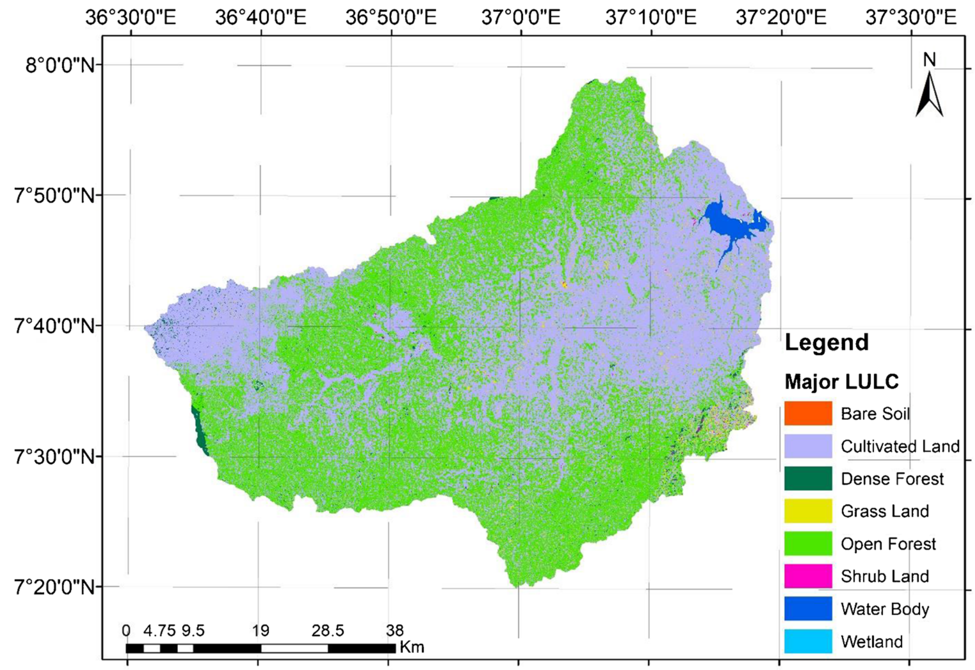


Fig. 3 LULC map of the study area

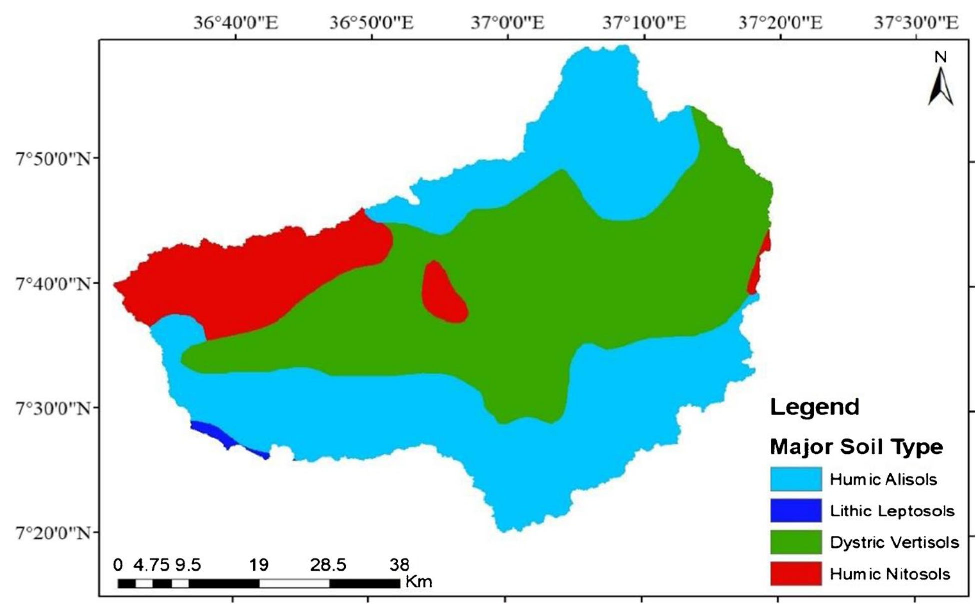


Fig. 4 Soil type of the study area

Methodology

The methodology used to evaluate the land suitability for surface irrigation was done following the standard of FAO guideline (FAO and UNEP, 1999) and accepted by land resource researchers all over the world (Malczewski, 2004; Nigussie et al. 2019 and Seif-Ennasr et al. 2020). And the factors that affect the suitability of an area for surface irrigation were identified based on previous studies, literature, and expert suggestions (FAO, 1996; USDIBR, 2005; Sultan, 2013 and Nigussie et al. 2019).

For this assessment, the spatial data (vector and raster data) of each land suitability factors were converted to the same cell size of each 30 × 30 m resolution raster dataset in ArcGIS database. Then, the factors were classified in to four suitability classes based on (FAO, 1996) land suitability framework, as highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and currently not suitable (S4) (Table 1). But, the weight of the effect of each factor on land suitability varied (FAO, 1996). So, the land suitability was determined by assigning different

Table 1 Framework of land suitability classification of (FAO, 1996)

Suitability order	Suitability class	Description
S1	Highly suitable	Land without significant limitations. This land is the best possible and does not reduce productivity or require increased inputs
S2	Moderately suitable	Land that is clearly suitable but has limitations that either reduce productivity or require an increase of inputs to sustain productivity compared with those needed on S1 land
S3	Marginally suitable	Land with limitations so severe that benefits are reduced and/or the inputs required to sustain production need to be increased so that this cost is only marginally justified
S4	Currently not suitable	Land that cannot support the particular land use on a sustained basis, or land on which benefits do not justify inputs

weights (ranks) to the factors that likely affect the irrigation potential of certain land area.

Once suitable physical land for irrigation is identified, the amount of available dry season flow of Gilge Gibe river (December to April) was determined and checked whether the flow is sufficient or not and come-up with the result of total irrigation potential of the study area.

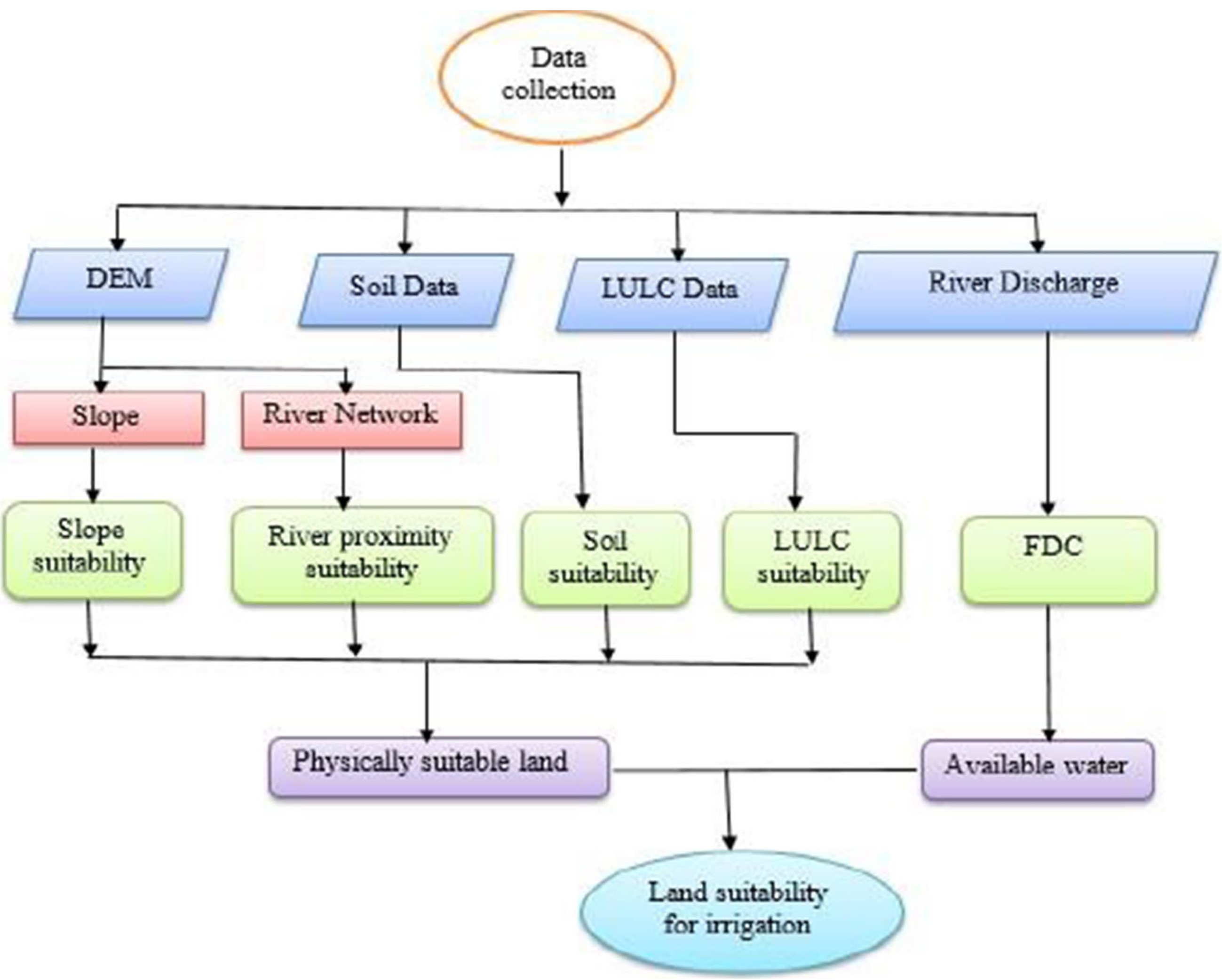


Fig. 5 General flow chart of land suitability analysis for surface irrigation

Figure 5 shows the general flow of the activity of work done to evaluate the suitability of land for surface irrigation.

Land suitability factors

The factors to be considered for a certain area varied based on the objectives of investigations and the particular level of the investigatory detail (USDIBR, 2005). For example, Kassaye et al. (2019) considered fifteen suitability factors such as soil pH, soil type, soil drainage, soil depth, available water storage capacity (AWSC), impermeable layer (IL), cation exchange capacity (CEC), electrical conductivity (ECE), phase, organic carbon (OC), texture classes (TC), obstacle to root crops (ORC), land use and land cover (LULC), slope (S), and distance from the river, and Worqlul et al. (2015) considered seven suitability factors like soil, land use, river proximity, urban proximity, road proximity, rainfall deficit, and slope. In this study also, major land suitability determining factors such as slope, river proximity, LULC, and soil type were considered.

Slope suitability

One of the most significant land suitability factor for irrigation is topography of the land. The flat area is considered to be highly suitable, whereas sloppy and undulating train area is considered to be not suitable for surface irrigation. So, this factor was computed from slope map of 30 × 30 m resolution digital elevation model (DEM) of the study area. Based on FAO and UNEP (1999), the slope map in percent was reclassified in to four suitability class for surface irrigation. Slope from 0 to 2% is classified as S1, from 2 to 4% as S2, and from 4 to 8% as S3, and slope above 8% is classified as S4 (Fig. 2).

River proximity suitability

River proximity is another significantly important factor that decides and prioritizes the areas to be suitable for surface irrigation. The nearer the distance to the river (except the buffer zone provided for the river), the more suitable for irrigation in terms of many factors such as cost of infrastructure, water loss, and slope. The main perennial river network in Gilgel Gibe catchment was extracted from DEM of 30 × 30 m resolution with watershed delineation process in ArcGIS 10.4. Suitability class of a land parcel with respect to river proximity was determined by its distance in relation to the perennial rivers. The distance from the rivers was calculated using Euclidean distance tool found in spatial analyst tool of ArcGIS 10.4. Then, the distance from the river was reclassified in to four categories (Halefom and Ulsido, 2020), which ranges 0–1.5 km, 1.5–3 km, 3–5 km, and > 5 km, and the suitability class was assigned accordingly. Hence, the closest distances were assigned as S1, and the farthest distances were assigned as S4.

LULC suitability factor

The land use and land cover (LULC) conditions of certain area determine the productiveness of an area for irrigation. The 2018 LULC data collected from (EMA) was used to consider LULC as land suitability factor. The collected data was in raster format consisting of about eight LULC types (Fig. 3). Based on the LULC data, more than half of the study area (54.14%) is covered with cultivated land followed by open forest (41%) (Table 2).

LULC suitability factor was generated by reclassifying the LULC map to four different ranges of suitability group based on their suitability for crop cultivation by irrigation (Verheye, 1976 and Worqlul et al. 2015). Accordingly, cultivated land was assigned as S1, grass land as S2, shrub land and open forest as S3, and dense forest, wetland, water body, and bare soil as S4.

Soil suitability factor

Soil is a key factor in determining the suitability of an area for agriculture and sustained irrigation (USDIBR, 2005 and Sultan, 2013). The soil map with attribute information of the study area was collected from MoWIE (Fig. 4). The collected data then arranged based on the FAO soil classification. Accordingly, the study area is covered with Humic Nitosols 11.93%, Dystric Vertisols 42.79%, Humic Alisols 44.92%, and Lithic Leptosols 0.36% (Table 3).

For this study, the soil suitability classes were determined based on Worqlul et al. (2015) suggestions and classification.

Table 2 LULC types and area coverage of study area

LULC type	Area (ha)	% area coverage	Suitability class
Cultivated land	188,819	54.14	S1
Open forest	143,061	41.02	S3
Grass land	9555	2.74	S2
Bare soil	29	0.008	S1
Dense forest	3839	1.101	S4
Shrub land	783	0.22	S3
Water body	2581	0.74	S4
Wetland	101	0.03	S4

Table 3 Soil type and area coverage of the study area

Soil code	Soil type	Are (ha)	% area coverage	Irrigation suitability
NThu	Humic Nitosols	41,624	11.93	S1
VRdy	Dystric Vertisols	149,238	42.79	S2
ALhu	Humic Alisols	156,652	44.92	S3
LPli	Lithic Leptosols	1255	0.36	S4

Accordingly, the soil which is naturally fertile and suitable for wide range of agricultural use like Humic Nitosols was classified as S1. Soils with good natural fertility and considerable agricultural potential were classified as S2. Humic Alisols with low moisture holding capacity and poor fertility were considered to be S3, and soil which is extremely gravely and stony nature is classified as S4.

Weighted overlay analysis of factors

Even though, the topography, soil type, river proximity, and LULC type are the major land suitability determining factors, the influence of each factor on land suitability is varied. This variation of the influence of the factor was differentiated by assigning weights for each factors. In this stage, the importance/preference of each factor relative to the rest of the factors on suitable land selection was expressed by assigning respective weights (Hussien et al. 2019).

The appropriate weights for each factor were determined and provided based on the literature of related work, observation, and based on experts' judgement. The pair-wise comparison logic developed by Saaty (1977) and improved by Connett et al. (2019) was used to give percent weight for each factor, under Analytical Hierarchy Process (AHP) technique with weighted linear combination. In the pair-wise comparisons, each factor was matched one-to-one with each other, and a comparison matrix was prepared to express the relative importance of one factor over the other, for the land suitability. The method was used by researchers including Malczewski (2004), Worqlul et al. (2015), and Seif-Ennasr et al. (2020). According to Saaty (1977), the scale of importance is ranged from 1 to 9 (Table 4). The highest value (9) corresponds to absolute importance one over the other, and reciprocal of it (1/9) shows an absolute triviality.

Once the intensity of the importance of one factor over the other is determined, then the pair-wise comparison matrix is prepared so that the factors are listed in row and column (Table 5). The column factor was compared with the factors in row for their significance for surface irrigation. After the pair-wise comparison matrix was filled in AHP extension of ArcGIS 10.4, the relative importance of the factors was computed in percent weight. Simultaneously, the consistency ratio (CR) which shows the judgement consistency of the user was also calculated by the AHP extension.

Surface irrigation potential assessment

The suitable surface land for irrigation was identified and determined by weighting the factors discussed above (in the "Weighted overlay analysis of factors" section). The weighting process of the factors was performed by using Arc GIS 10.4, weighted overlay tool of spatial analyst tool. While performing the weighted overlay analysis, the weight of each factor (percent weight values) was provided to each of the respective factors. Then, a preliminary suitable surface of land for irrigation was computed. Finally, the restricted areas which are defined as permanently not suitable for irrigation as FAO guideline, (Verheye, 1976) framework, were deduced from the map using erase tool of analysis toolbox

Table 5 Pair-wise comparison matrix

Factors	Slope	River proximity	LULC	Soil
Slope	1	3	5	7
River proximity	1/3	1	3	5
LULC	1/5	7	1	3
Soil	1/7	1/5	1/3	1

Table 4 Pair-wise comparison scales and definitions

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective
3	Somewhat more important	Experience and judgement slightly favor one over the other
5	Much more important	Experience and judgement strongly favor one over the other
7	Very much more important	Experience and judgement very strongly favor one over the other. Its importance is demonstrated in practice
9	Absolutely very important	The evidence favoring one over the other is of the highest possible validity
2,4,6,8	Intermediate values between two adjacent judgement	When compromise is needed

in Arc GIS 10.4. Such areas include, urban area, restricted forest, water bodies, and wetland.

Crop water requirement

The crop water requirement (CWR) for the whole growing period of the crops was determined using the CROPWAT 8 software, which is developed by FAO in 1992 (Sciences, 2019). To estimate average monthly value of reference evapotranspiration (ET_o) for the crops, climatic data such as minimum and maximum temperature, humidity, wind speed, and sunshine hour were used as an impute.

In the study area, the dominant crops grown and cultivated through irrigation are tomato, potato, maize, millet, and small vegetables by rotation throughout the dry season. Hence, these crops and vegetables crop coefficient (Kc) values were considered while calculating maximum evapotranspiration (ETc) using the equation below (Eq. 1). After monthly CWR is calculated, gross irrigation requirement (GIR) was determined from CWR by considering irrigation efficiency (e_i) of 60% to account different losses (Nigussie et al. 2019) which include application loss and conveyance loss (Eq. 2).

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

where ETc is crop evapotranspiration, Kc is crop coefficient, and ETo is reference evapotranspiration

$$GWR = \frac{CWR}{e_i} \quad (2)$$

where GWR is gross water requirement, CWR is crop water requirement, and e_i is water application efficiency.

Surface water availability

To determine total irrigation potential of a certain area, determination of suitable surface land for irrigation (determine in the "Surface irrigation potential assessment" section) and quantification of water available nearby the suitable surface area is important. In the study area, the demand of irrigation water is high during dry season (time of low flow of rivers) and low to nil during wet season. So, the information on low flow of the river was required to quantify the amount of water available for surface irrigation application during dry season. Hence, the low flow of the Gilgel Gibe River was computed from recorded average daily discharge data for the year 1990 to 2013. The daily discharge data, which is obtained from the MoWIE, was converted to monthly average data. Then, the low flow characteristics of the river were estimated using flow duration curve (FDC) which enables to determine the 90 percent (%) available flow. The 90% flow is described as the flow exceeded 90% (Q90) of the time for a particular year (Worqlul et al. 2015). Hence, the 90% available flows were determined by ranking all average monthly flow data and finding the discharge exceeded by 90% of all values (Reilly and Kroll, 2003; Eslamian et al. 2010).

Result and discussion

Irrigation suitability factors

In order to assess the surface irrigation potential of the study area, the topography, soil type, land use land cover, and the availability of water with reasonable distance were considered. But the influence of these factors on the suitability of the land is varied. Hence, the weight of the influence of each factor was determined and used as recommended by FAO's standards and previous studies.

Slope suitability factor

Slope is the principal topographic characteristics which determines the suitability of land for surface irrigation. It influences the suitability of an area in terms of land preparation for irrigation and irrigation activities (USDIBR, 2005). Hence, the slope map of the study area was classified in a range recommended by USDIBR (2005) for land suitability. Based on the classification result of slope for irrigation suitability, about 15,871 ha (4.55%) of land was found to be categorized under highly suitable, and an area of 263,504 ha (75.55%) is found to be not suitable. The intermediate between the two extreme class was moderately and marginally suitable area which covers about 18,880 ha (5.41%) and 50,526 ha (14.49%) of land respectively (Fig. 6a). This result shows that most part of the study area is characterized by undulating topography which is not favorable for surface irrigation. As this factor is the most significantly determining factor for surface irrigation with a factor weight of 56% (Tables 6, 7, 8, 9, and 10), it made the overall irrigation potential, particularly, the highly suitable class of the study area to be less.

River proximity factor

The river proximity factor is very influential factor for land suitability as the water is considered to be taken from the rivers. Hence, the nearest area was considered to be highly suitable (S1) and the farthest area was considered to be not suitable (S4) for irrigation (Worqlul et al. 2015). Hence, the reclassification result indicated that about 108,771 ha (31.18%) of land was found to be nearer to the rivers and considered as highly suitable, and about 76,247 ha (21.85%)

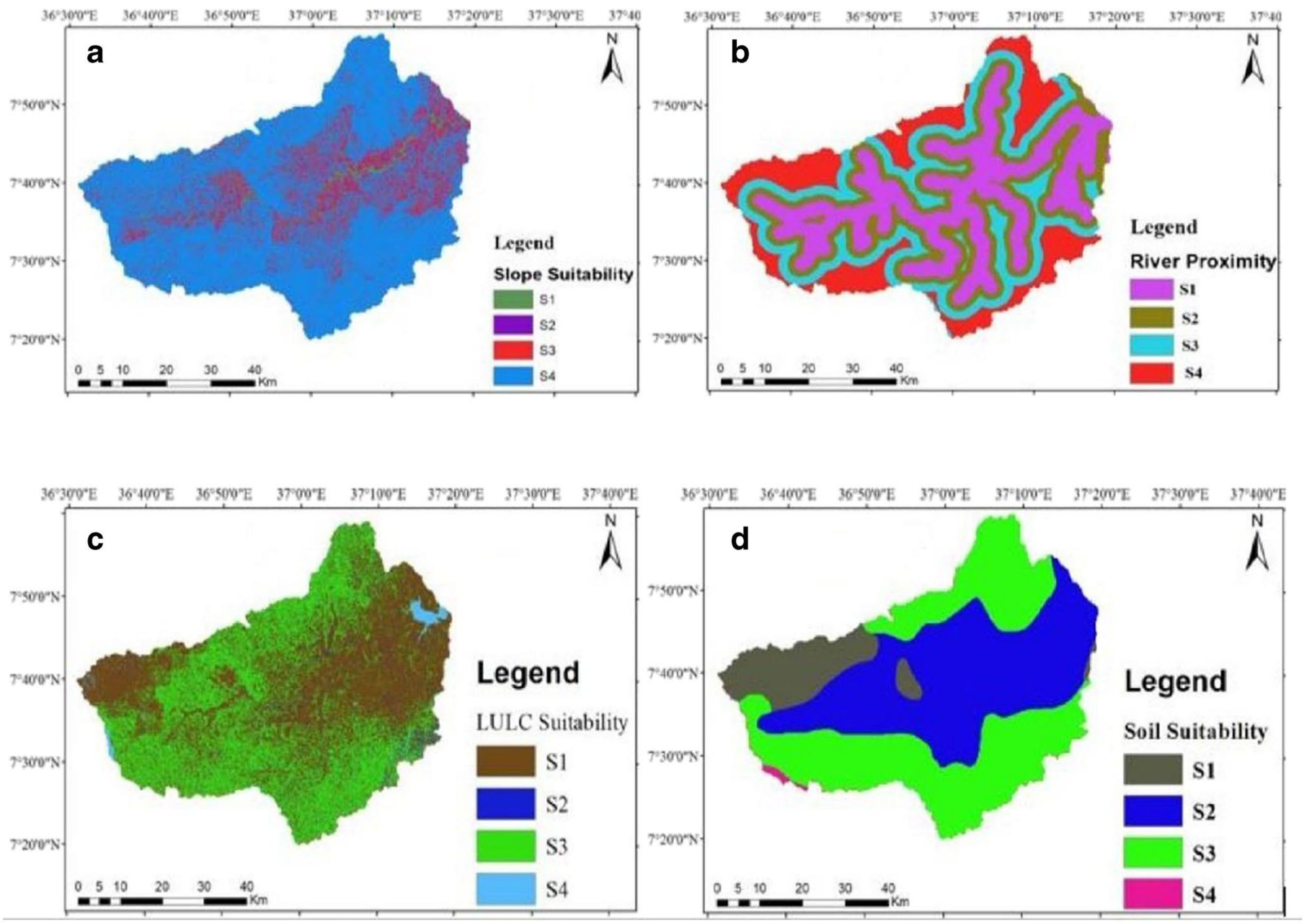


Fig. 6 Land suitability factors map. Slope suitability (a), river proximity suitability (b), LULC suitability (c), and soil suitability (d) map

Table 6 Slope suitability class

Slope range in percent	Slope suitability class	Area (ha)	% area coverage
0–2	Highly suitable (S1)	15,871	4.55
2–4	Moderately suitable (S2)	18,880	5.41
4–8	Marginally suitable (S3)	50,526	14.49
> 8	Not suitable (S4)	263,504	75.55
		348,769	100

was found to be located considerably far from the rivers and considered as not suitable (Fig. 6b). The remaining 88,483 ha (25.37%) and 75,293 ha (21.59%) of land is found under moderately and marginally suitable range respectively (Table 7).

LULC suitability factor

The LULC type influences the suitability of land for irrigation. To determine the LULC factor, the LULCs that show the same or nearly the same influence on suitability categorized under the same suitability class (Worqlul et al. 2015). It means, cultivated land was categorized under highly suitable class and water body; wetland and dense forest were considered as non-suitable class (Table 8). Based on the classification result of the LULC suitability class, about 188,830 ha (54.14%) of land is

Table 7 River proximity land suitability class

Distance from the rivers (km)	Suitability class	Area (ha)	% area coverage
0–1.5 (excluding buffer zone)	Highly suitable (S1)	108,771	31.18
1.5–3	Moderately suitable (S2)	88,483	25.37
3–5	Marginally suitable (S3)	75,293	21.59
> 5	Not suitable (S4)	76,247	21.86

Table 8 LULC suitability classification

LULC type	LULC suitability class	Area (ha)	% area coverage
Cultivated land	Highly suitable (S1)	188,830	54.14
Grass land	Moderately suitable (S2)	9550	2.74
Open forest and shrub land	Marginally suitable (S3)	143,873	41.25
Dense forest, water body wetland, and bare soil	Not suitable (S4)	6513	1.87
Total		348,769	100

Table 9 Soil suitability class

Soil type	Suitability class	Area (ha)	% area coverage
Humic Nitosols	Highly suitable (S1)	41,624	11.93
Dystric Vertisols	Moderately suitable (S2)	149,238	42.79
Humic Alisols	Marginally suitable (S3)	156,652	44.92
Lithic Leptosols	Not suitable (S4)	1255	0.36
Total		348,769	100

Table 10 Weights of each determining factor

Factors	Weight (%)	Rank
Slope	56	1
River	26	2
Soil	11	3
LULC	7	4
CR	0.043	

categorized as highly suitable, and 6513 ha (1.87%) is categorized under not suitable class (Fig. 6c). The remaining 9550 ha (2.74%) and 143,873 ha (41.25%) of land is classified under moderately and marginally suitable area, respectively.

Soil suitability factor

The characteristics of soil influence the suitability of the area for irrigation. Its primary influence is on the productive capacity and development of irrigation area. The soil suitability in the study area was evaluated based on Worqlul et al. (2015) soil suitability evaluation criteria. Based on the result of the classification, about 41,624 ha (11.93%) of land was covered with highly suitable, and 1255 ha (0.36%) of land is covered with the soil totally not suitable for crop cultivation (Fig. 6d). The remaining area is covered by 149,238 ha (42.79%) and 156,652 ha (44.92%) of land, which are moderately and marginally suitable, respectively (Table 9).

Weighting of the factors and suitable area for irrigation

A preliminary surface irrigation suitable area was computed by weighting the determining factors (slope, river proximity, LULC, and soil) by applying the pair-wise comparison matrix as shown in Table 5. Subsequently, the credibility of the par-wise comparison matrix consistency was evaluated using the consistency ratio (CR). The result of CR was found to be reliable with value of 0.043. The value of CR is in the acceptable limit (Saaty, 1977; Chen, 2006 and Worqlul et al. 2015), which ranges from 0 to 0.1, for the consistency of judgment of the weights of factors.

Based on the result of the analysis, physically suitable land and its suitability range for surface irrigation are shown in Fig. 7 and Table 11. Figure 7 clearly shows that the highly suitable portion of land is situated along the side of rivers, and the non-suitable area is found far from the rivers. It is because the topography of the area which is far from the rivers is highly undulating (up and down terain), while the area nearer to the rivers relatively characterized by flatten and flatten with gentle slope. As both, slope and river proximity factors are more important deciding factors (Worqlul et al. 2015) for land suitability than others; the result is more significantly influenced by these factors. It means that the more the closer to the river, the more suitable will be the land and vice versa. Naturally, most of the study area topography possesses undulating nature of the terain. Hence, the highly suitable area for surface irrigation is very small compared to a result founded by (Mandal et al. 2018) (22.53%) and (Kassaye et al. 2019) (11.7%) for Kansai watershed, Purulia, West Bengal, India, and Erer Watershed, Eastern Hararghe Zone, Ethiopia, respectively.

Generally, as can be seen from Table 11, only 8723 ha (2.64%) of land was found to be highly suitable, and 80,772 ha (24.48%) of the area was found to be non-suitable for surface irrigation. In between the two extremes, about 48,190 ha (14.61%) and 192,252 ha (58.27%) of land were categorized under moderately and marginally suitable category for surface irrigation. So, most of the area (58.27%) laid under the category of marginally suitable which means land with limitations so severe that benefits are reduced and/or the inputs required to sustain production need to be

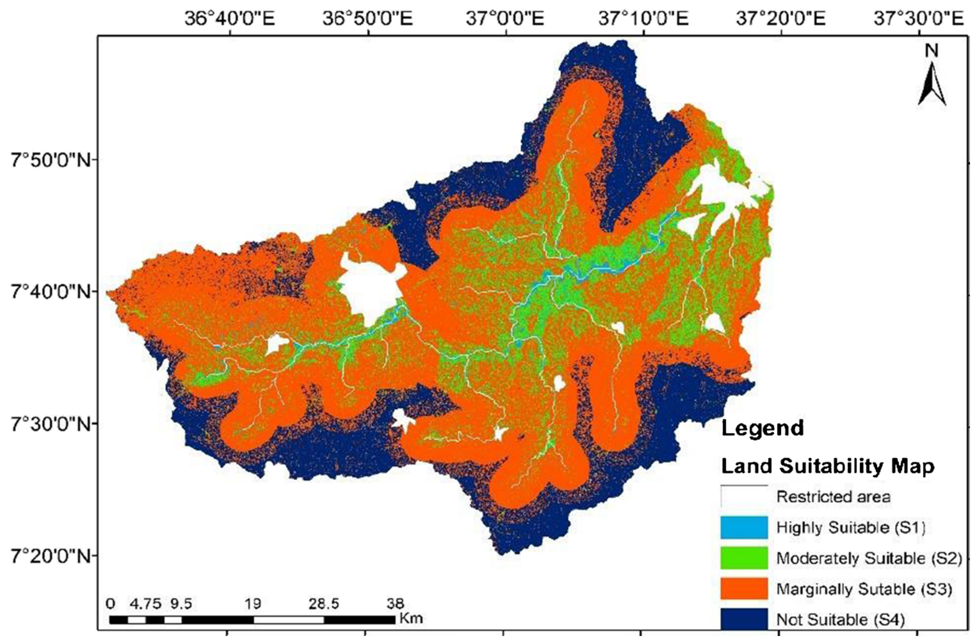


Fig. 7 Land suitability map

Table 11 Area distribution of suitability classes

Land suitability class	Area (ha)	% area coverage
Highly suitable (S1)	8723	2.64
Moderately suitable (S2)	48,190	14.61
Marginally suitable (S3)	192,252	58.27
Not suitable (S4)	80,772	24.48
Total	329,937	100

increased so that this cost is only marginally justified (FAO, 1996).

Surface water availability and crop water requirement

In the study area, the water requirement for irrigation is high during dry season (time of low flow of rivers) and low to non during rainy season (Table 12). So, the amount of low flow of the river was required to quantify the amount of water available for surface irrigation application during dry season. Hence, the low flow of the Gilgel Gibe River

Table 12 Surface water availability and water requirement

Months	Monthly CWR (m^3/month/ha)	90% available river flow (m^3/month)	Total land that can be irrigated by the available water (ha)	% area that the dry flow can irrigate (S1)	% area that the dry flow can irrigate (S1 + S2)	% area that the dry flow can irrigate (S1 + S2 + S3)
Jan	1365.98	24,456,470.40	17,903.92	205.25	31.46	7.19
Feb	1128.96	22,089,715.20	19,566.43	224.31	34.38	7.85
Mar	1517.76	24,456,470.40	16,113.53	184.72	28.31	6.47
Apr	1296.00	23,667,552.00	18,262.00	209.35	32.09	7.33
May	89.28	24,456,470.40	273,930.00	3140.32	481.31	109.94
Jun	0.00	23,667,552.00	*	*	*	*
Jul	0.00	23,667,552.00	*	*	*	*
Aug	0.00	23,667,552.00	*	*	*	*
Sep	86.40	23,667,552.00	273,930.00	3140.32	481.31	109.94
Oct	714.24	24,456,470.40	34,241.25	392.54	60.16	13.74
Nov	1382.40	23,667,552.00	17,120.63	196.27	30.08	6.87
Dec	1696.32	24,456,470.40	14,417.37	165.28	25.33	5.79

Where * indicates no irrigation in the specified months.

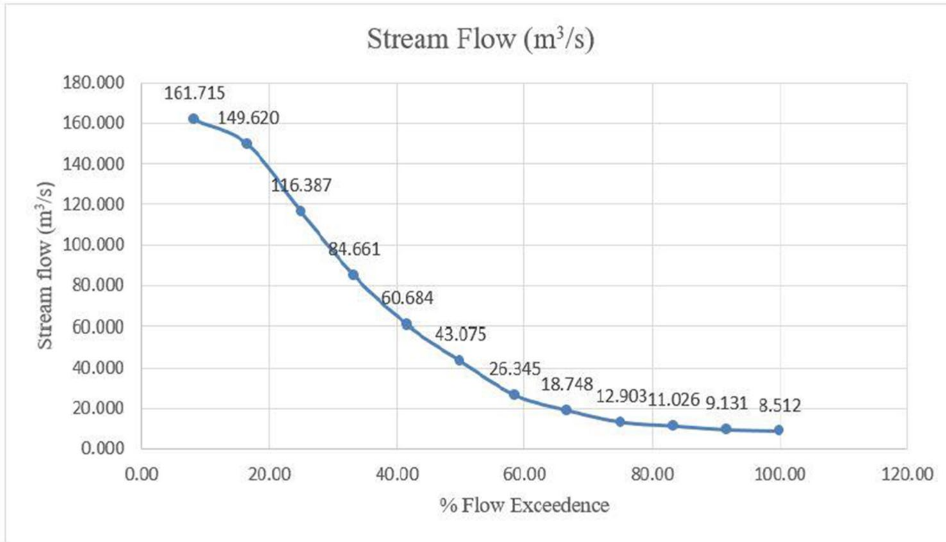


Fig. 8 Flow duration curve of Gilgel Gibe River

was computed by the technique known as flow duration curve (FDC) method. FDC for Gilgel Gibe River was generated from the recorded average daily discharge data of the year 1990 to 2013 (Fig. 8). The FDC enables to determine the 90% of time available flow. The 90% available flow is described as the flow exceeded 90% (Q90) of the time for a particular year (Worqlul et al. 2015). Hence, the 90% available flows were determined by ranking all average monthly flow data and finding the discharge exceeded by 90% of all values (Reilly and Kroll, 2003; Eslamian et al. 2010).

As shown on the figure above (Fig. 8), the 90% available flow was found to be 9.13 m^3/s. Hence, the irrigation potential/capacity of the 90% available flow was computed by dividing this flow of water (90% available flow) by average monthly crop water requirement (CWR) for each month. So, the net irrigation potential of the study area was determined by considering two things. The first one is, amount of available low flow of the river. And the second one is, physically suitable land surface which is determined above (the "Weighting of the factors and suitable area for irrigation" section). So, the result of this study is presented based on the capability of the 90% available flow of river, to irrigate the identified irrigable area on a monthly base. Hence, the result indicated that the river has a potential of irrigating the first suitability class (S1) area which covers only 8723 ha (2.64%) fully and sustainably throughout the year. In the month of January, the river has no sustainable capability to irrigate the first two suitability class (S1 and S2). The highly suitable and moderately suitable area covers about 56,913 ha while the river has a capability of irrigating 17,903.92 ha, which is only 31.458% in the month of January. In the same way, the river has a capability of irrigating only 7.19% of the total irrigable area (S1 + S2 + S3) in the month of January with an average monthly CWR of 0.51 l/s/h (1365.98 m^3/month/ha). The capability of the river flow in different months of the year is given in Table 12. On the other hand, the river has a minimum potential of irrigation at a season of low flow. In the month of December, the river has a potential of irrigating only 14,417.37 ha; this is because, in the month December, the crop water requirement is very high, and the flow is low. The river irrigation potential is becoming increased from March to May because of the crop water requirement (CWR) becoming decreased from March to May and finally become nil crop water requirement (CWR) starting from June to September which is wet season in this area.

Conclusion

In this study, the irrigation potential of Gilgel Gibe watershed was evaluated based on the assessment of both the land suitability and water availability for surface irrigation. The land suitability was evaluated, considering major factors, which affect suitability of land for surface irrigation. These factor includes slope, river proximity, soil type, and LULC type. And then, the suitable land was identified by aggregating the effect of all factors by overlaying the factors map in ArcGIS Environment. The water availability was determined by considering the low flow of the river by generating FDC from historical measured flow data. Hence, the result indicated that Gilgel Gibe watershed has a potential of 249,165 ha (75.52% total area) of irrigable land, which includes S1, S2, and S3. But, the highly suitable land (S1) is relatively small, which is only 8723 ha (2.64% of total area). This is due to the topography of the watershed, which is highly up and down, which is also influenced by the slope factor, indicating only 4.55% of land is highly suitable for surface irrigation. On the other hand, the river has a minimum potential of irrigation at a season of low flow. For instance, in the month of December, the river has a potential of irrigating only 14,417.37 ha. So, future expansion of irrigation up to full irrigation potential of the Gilgel Gibe basin, there should be a construction of dams across the river to store runoff during the rainy season.

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Declarations

Conflict of interest The author declares no competing interests.

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