American Journal of Civil Engineering
2021; 9(4): 127-137
http://www.sciencepublishinggroup.com/j/ajce
doi: 10.11648/j.ajce.20210904.14
ISSN: 2330-8729 (Print); ISSN: 2330-8737 (Online)

GIS-Based Irrigation Potential Assessment for Surface Irrigation: The Case of Birbir River Watershed, Oromia, Ethiopia

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To cite this article:
Garuma Negasa. GIS-Based Irrigation Potential Assessment for Surface Irrigation: The Case of Birbir River Watershed, Oromia, Ethiopia. *American Journal of Civil Engineering*. Vol. 9, No. 4, 2021, pp. 127-137. doi: 10.11648/j.ajce.20210904.14

Received: June 25, 2021; **Accepted**: July 16, 2021; **Published**: August 24, 2021

Abstract: The assessment process of surface irrigation has to integrate information about the suitability of the land; water resource availability and water requirements of irrigate able areas in time and place. Birbir River is one of well-known river found in western Ethiopia. The Birbir River is a tributary of the Baro-Akobo river basin, which creates Baro River when it joins with Gebba River. Ethiopia has immense potential in expanding irrigation using available water resources. But due to lack of information related to cultivable and irrigation suitability of the land, its agricultural system does not yet fully productive. Geographic Information System can be an effective tool in identifying irrigable land and mapping of suitable land for irrigation. Therefore, the objective of the present study was to assess the surface irrigation potential of the Birbir river watershed using ArcGIS 10.3. Different methods of data processing and analysis have been employed in this study. The main suitability factors used to identify the potential irrigable land for surface irrigation were slope, soil texture, soil depth, soil type, soil drainage characteristics, land use, land cover and distance to water source. The consistency of rainfall and stream flow data were checked by double mass curve and the areal mean of rainfall and temperature data were determined by using Theissen polygon method whereas the irrigation water demands of the selected two crops (maize and potato) were calculated separately using FAO cropwat model. By weighting values of the seven factors using Analytic Hierarchy Process and overlaying by weighted overlay in ArcGIS 10.3, the irrigation suitability map was developed and potential irrigable land for surface irrigation was found to be 17%, 63% and 20% for highly suitable (S1), moderately suitable (S2), and marginally suitable (S3) respectively. Irrigation potential of the Birbir river watershed was obtained by comparing monthly gross irrigation requirements of the identified land suitable for surface irrigation and the available 80% mean monthly dependable flows in the river catchments. The potential irrigable land that can be irrigated without provision of storage structures was found to be around 68,000 ha from the total of 106,223 ha suitable land for surface irrigation.

Keywords: Birbir River Watershed, Digital Elevation Model, Geographic Information System, Irrigation Land Suitability, Suitability Parameter

1. Introduction

Currently, the earth's population is growing dramatically. Today's world population of 7.6 billion is expected to reach about 11.1 billion by the end of 2100. This growing population will result in considerable additional demand for food [1]. FAO analyzed agricultural production for over 90 less developed country, and the result showed that from a period of 1998 to 2030 it increases by 49% in rain-fed agriculture and by 81% by irrigation. Therefore, a higher number of additional foods are expected from an irrigation system [2]. Ethiopian Central Statistical Agency conducted Ethiopia's population in 2016 and estimated at 98,352,000 million and most of the people in Ethiopia lives in the highland area, with 85 percent being rural and dependent on agriculture with a low level of productivity [3]. Agriculture is the basis for the economy of Ethiopia. Agriculture accounts for the employment of 90% of country’s population, over 50% of the country’s gross domestic product (GDP) and over 90% of foreign exchange earnings [4]. About 15 to 17% of

Government expenditures are committed to the agriculture sector [5]. Ethiopia receives about 980 billion cubic meters (m^3) of rain per year and its agricultural system does not yet get fully benefit from the technologies of water management and irrigation [6]. Even though Ethiopia has been proved to be the" water tower of Africa" the use of this resource is not practiced well in the country. It is estimated that greater than 90% of the food supply in the country comes from low productivity rain fed agriculture and hence rainfall is the single most important determinant of food supply and the country's economy. However, rainfall in Ethiopia is varying highly and erratic in time and space [7]. As a consequence, precipitation is generally insufficient to sustain the agriculture needed to alleviate food insecurity, and it becomes very important to develop and manage all other available water resources. Water has been recognized as the most important factor for the transformation of low productive rain-fed agriculture into most effective and efficient irrigated agriculture [8].

Considering the available water and land resources of the country, Ethiopia has immense potential in expanding irrigated agriculture. In 2011, Ethiopian Ministry of Agriculture conducted the study on small scale irrigation situation analysis and capacity needs assessment on irrigation and found that, the totals irrigate able land in the country measures 3.7 Mha. Despite this irrigation potential which is estimated to be about 3.7 million ha, only about 190,000 ha (5.3% of the potential) is currently under irrigation, which plays insignificant role in the country's agricultural production [9]. The country has planned to develop 15.4% of the potential at the end of 2021, which will boost irrigate able land of the country to 1,721,819 ha [10]. The main capital investment on surface irrigation system is mainly associated with land grading, but if the topography is not too undulating, these costs are not high. Hence, surface irrigation development requires favorable topography and information on land and water resources for proper planning [11]. Therefore, planning process for surface irrigation has to integrate information about the suitability of the land; water availability and water requirements of irrigate able areas in time and place [12]. According to the study conducted by ministry of water resource in (2009), Ethiopian mountains are the source of most rivers (Abay, Awash, Tekeze, Mereb, Baro, Gilo, Akobo and Omo rivers) that flow to the west and southwest. Determining the suitability of land for surface irrigation requires thorough evaluation of soil properties and topography (slope) of the land within field [13]. Most of the time, attention is given to the physical properties of the soil, the distance from available water sources and the terrain conditions in relation to methods of irrigation considered [14]. In addition to these factors, land use / land cover types are considered as limiting factors in evaluating suitability of land for irrigation [15]. Geographic information system (GIS) and remote sensing (RS) technological applications have now become the common place for the utilities, land information and planning. GIS can be an effective tool in identifying irrigates able land and mapping of suitable land for irrigation. RS and GIS tools were widely used for the management of water resources [16]. Considering the importance of RS and GIS techniques, the present study was undertaken to assess a surface irrigation potential of Birbir river watershed by evaluating different parameters.

2. Objective of the Study

The general objective of this study was to assess surface irrigation potential in Birbir river watershed using Geographic Information System technique.

3. Research Methodology

3.1. Study Area Description

Birbir river is one of well-known river found in western Ethiopia. The Birbir river is a tributary of the Baro-Akobo river system, which creates Baro river when it joins the Gebba river at latitude 8°14′28″N and longitude 34°57′39″E. The Birbir river watershed covers an area of 634,415 ha of land. It is located between the geographical coordinates of 8°27′11″ to 9°24′25″N latitude and 34°42′54"to 35°50′52″E longitude. It is located at a distance of 490 km from Addis Ababa. The annual mean minimum and maximum temperature ranges are 12.0°C to 16°C and 23.1°C to 31°C respectively. Rainfall in the region generally varies with altitude. The annual rainfall of the watershed is ranging from 1500 to 1800 mm. The agro-climatic condition of the areas alternates with long summer rainfall (June to September) and winter dry season (December to March). The altitude ranges from 1300 to 1800 m.a.s.l.

3.2. Data Collection

Data necessary for the modeling the work, such as monthly meteorological data (rainfall, temperature, relative humidity, and wind velocity and sunshine hours) of 24 years period were collected from National Metrological Service Agency (NMSA) of the country. A request for monthly meteorological data (rainfall, temperature, relative humidity, wind velocity and sunshine hours) data of 30 years period was made to the agency. Following the approval of the agency's higher official monthly data of up to 24 years period used in the model work were collected. From the all available automatic recording stations, 6 stations were selected, which are approximate in and near to the watershed, were considered for this research work. These 6 stations are Alge, Ayiraa, Yubdoo, Gimbii, Goree and Chanqa. Hydrological data were obtained from the Ministry of Water, Electricity and Energy, Hydrology Department. Data were preliminarily collected for gauging stations with catchment size not exceeding 2800 km^2, based on the recommendation of [17]. About 4 gauging stations with continuous water level records are available in the basin. The records of these stations are Keto, Ouwa, Yubdo and Chanka. The watershed physiographic data such as records on Soil, Land use, Land cover, and Slope and Drainage systems were collected from

Ethiopian Ministry of Water, Electricity and Energy, GIS and remote sensing department. DEM with pixel size of 30mx30m was collected from Ethiopian Map Agency. The projections of the map collected were Universal Transverse Mercator (UTM). The classifications of these physiographic data were done by GIS and Remote Sensing Department of the Ethiopian Ministry of Water, Electricity and Energy. The researcher collected the classified data and only reclassification in accordance with recommendation of [25] was done by the researcher. Materials and software used in this research were CROPWAT 8.0, New LocClim 1.1, SWAT, ArcGIS 10.3 and Geographic Position System (GPS).

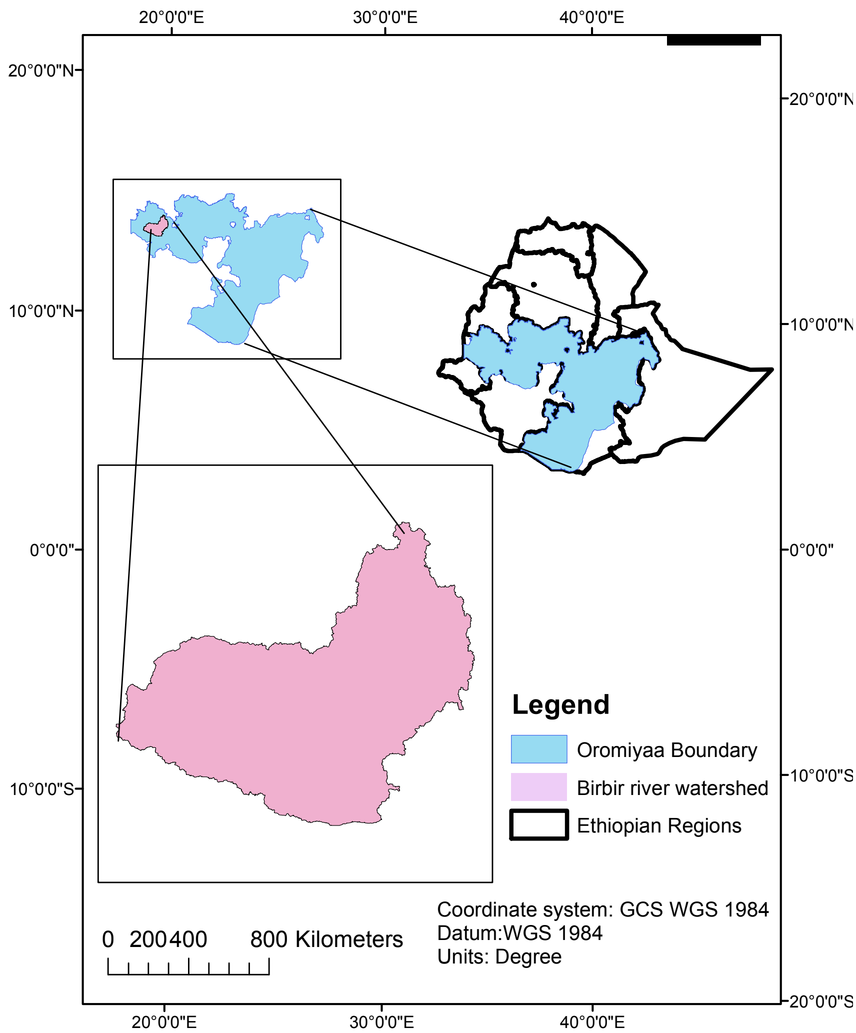

Figure 1. *Location map of Birbir River.*

3.3. Data Availability Statement

Data necessary for the modeling work were collected by the researcher from different government departments, monthly meteorological data of 24 years period such as rainfall, temperature, relative humidity, and wind velocity and sunshine hours were collected National metrological service agency of Ethiopia (NMSAE) without any payment. Hydrological data (stream flow data) were obtained from the Ministry of Water, Electricity and Energy, Hydrology Department. The watershed physiographic data were obtained from Ethiopian Map Agency. Records on soil, land use land cover, slope and drainage systems were obtained from Ethiopian Ministry of Water, Electricity and Energy, GIS and remote sensing department. The researcher can approve there is no restrictions on sharing or applying of materials used in this research. Some data, models, or code used during the study were provided by a third party. A direct request for these materials was made to the provider as indicated in the Acknowledgements. Based on this, data of records on soil, land use land cover, slope and drainage system can be obtained from Ethiopian Ministry of Water, Electricity and Energy and physiographic data can be obtained from Ethiopian Map Agency. In addition to this some data such as Meteorological data, Hydrological data (stream flow data) are available from the author upon reasonable request.

3.4. Methods of Data Processing and Analysis

Different methods of data processing and analysis have been employed in this research. Identification of suitable sites for surface irrigation was carried out by considering the slope, soil type (fertility), soil texture, soil drainage, soil depth, land cover/use and distance between water supply and the potential command area as factors. The individual suitability of each factor was first analyzed and finally weighted to get suitable irrigable sites. Finally according to the research objectives suitable land map for irrigation was prepared based on GIS analysis.

3.5. Watershed Delineation

In Birbir river watershed delineation, the DEM with 30x30 pixel size, which provides topographic information of the watershed, was used. The study area was delineated using "Soil and Water Assessment Tool Software" which is GIS interface. The delineated Birbir river watershed covers a total area of 634,415 ha.

3.6. Pre-Processing and Checking Data

To prepare input data for water resources assessment and irrigation water requirement estimation using the CROPWAT model, meteorological data and stream flow data were checked for errors. Screening of the both metrological data (rainfall, temperature, relative humidity, and wind velocity and sunshine hours) and stream flow data in the study area were done by visual inspection and some data contains errors due to failures of measuring devices or the recorder. There was short period missing in rainfall records of four stations (Alge, Ayiraa, Gimbii and Goree) and stream flow data missing in gauge stations such as Chanka and Yubdoo. These missing rainfall data and stream flow data analysis was conducted for each station to fill the unavailable data. A number of methods have been proposed to estimate the missed data. In this research because of the lack of the total annual rainfall and normal rainfall, which were necessary conditions for the two methods (normal ratio and station average methods), the regression method was found to be good method of estimation to fill the missed data. This method is also good for short period of data missing. If the conditions relevant to the recording of a gauge station have undergone a significant change during the period of record, inconsistency of data would arise in the data of that station. In this study the checking for inconsistency of a record was done by double mass curve technique. The computation of average areal input data of meteorological data were calculated by the Thiessen polygon method using ArcGIS 10.3. This method assumes that at any point in the watershed the point data is the same as that at the nearest gauge so the depth recorded at a given gauge is applied out to a distance halfway to the next station in any direction [18]. This method is selected because; the two methods (arthimetic average and isohyetal methods) failed to fulfill the criteria.

3.7. Irrigation Water Requirements Computation

Irrigation water requirement of the potentially irrigate able site (command area) was computed using the CROPWAT 8 software. Crop types such as potato, garlic, onion and maize are commonly grown in the study area were selected for knowing crop data like length of growth stages, crop coefficient (Kc) and root depth at different growth stages. The crop coefficients for these crops were selected based on [19]. Two crops, maize and potato were selected to estimate the water demand on monthly basis. These crops were selected based on their suitability for irrigation practice and their extent in comparing with other irrigated crops grown in the area. In addition to this these two crops can be cultivated on wider area than other crops and their evapotranspiration is greater than other crops. Meteorological data such as temperature (maximum and minimum), rainfall, wind speed, sunshine hours and relative humidity were used as data input in CROPWAT 8 software. In addition to climate data inputs crop and soil data were used to compute crop water requirements. Then the gross irrigation water requirements of the crops at the identified potential irrigable sites were estimated by considering application efficiency for surface irrigation and water conveyance efficiency.

3.8. Identification of Suitable Irrigable Lands

In order to identify suitable land for irrigation determinant factors such as, slope, land use, soil type, water availability and accessibility need to be considered [20]. Identification of suitable sites for surface irrigation was carried out by considering seven suitability factors such as e slope, soil type, soil texture, soil drainage, soil depth, land cover/land use and distance between water supply and the potential command area. The individual suitability of each factor was first analyzed and finally weighted to get suitable irrigable sites.

3.8.1. Slope Suitability Analysis

The slope map of the watershed was derived using the "Spatial Analysis Slope" tool in ArcGIS 10.3. The Slope that had been derived from the DEM was classified based on the classification system of [25] using the "Reclassification" tool, which is an attribute generalization technique in ArcGIS 10.3. The four suitability ranges or slope suitability criteria are highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N) for surface irrigation. Accordingly, slope suitability classes with the factor rating of S1, S2, S3, and N were described in Table 1.

Table 1. *Slope suitability classifications for surface irrigation [25].*

S. No	Slope (%)	Slope class	Factor rating
1	0-2	Level	S1
2	2-5	Undulating	S2
3	5-8	Undulating	S3
4	>8	Rolling-hill	N

3.8.2. Soil Suitability Assessment

To assess soil suitability for irrigation, FAO- soil map of east Africa was used. The major soil types, soil depth, soil drainage and soil texture in the watershed were then reclassified. By considering those soil physical parameters, irrigation suitability of the Birbir watershed was evaluated independently based on the [21-23] soil classification guideline. Accordingly, soil suitability classes for each parameter with the factor rating of S1, S2, S3, and N were described in Table 2. Physical properties of these soil groups were used for irrigation suitability analysis. The rasterized soil map of the watershed was then reclassified based on their soil type name, texture, and depth and drainage class.

3.8.3. Land Use Land Cover Analysis

The type of land use and land cover of the watershed was ranked based on their importance for surface irrigation potential, costs to remove or change for cultivation and environmental impacts under the watershed. According to [21], which are widely used to classify land suitability for specified objectives of land utilization types, a land can be divided in to five classes. These include very suitable (S1), suitable (S2), marginally suitable (S3), marginally not suitable (N1) and permanently not suitable (N2).

3.8.4. Distance from Water Supply

To identify irrigable land close to the water supply (Birbir river), straight-line (Euclidean) distance from watershed outlets were calculated using DEM of 30 m × 30 m cell size by using the buffer icon in the analysis tool and clip to the specified study area. The clipped map of the buffer was then converted to raster using the conversion tool and reclassified in to suitability class based on its distance to the water source used "Reclassified tool". The reclassified distance was used for weighting overlay for further analysis together with other factors. Distance between the source of the water and the command area needs a subjective judgment in deciding the buffer distances. However, the following factors were considered in order to decide the distance between the command area and source of water. These factors are: power capacity of the pumping engine, cost for the high power pumping engines, cost for construction of canals, cost of maintenance of canals and cost of water lost from canal especially for small scale and medium scale irrigation.

3.9. Weighing of Irrigation Suitability Factors

To reduce the individual biases of factor weighting, the weights in the study were determined by using a pairwise comparison method as developed by Saaty (1980) in the context of the Analytical Hierarchy Process (AHP). All the seven factors, which were selected for the evaluation of land suitability in the study area, were weighted using pair wise comparison. Land classification the parameters are weighted and ranked as follows in table 3.

Table 2. *Soil suitability factor rating for surface irrigation suitability [22].*

Soil factors	**Factor rating**			
	S1	**S2**	**S3**	**N**
Drainage class	Well	Moderate	Imperfect	Poor to very poor
Depth (cm)	>100	80-100	50-80	<50
Texture	Loam-Silty Cay, Clay	Silt loam, Sandy Cay	Sandy, sandy loam	

Table 3. *The standardized results and weight of all seven parameters.*

Factors	**Slope**	**Land cover**	**Soil depth**	**Soil drainage**	**Soil texture**	**Soil type**	**Distance**	**Weight (%)**
Slope	1	3	3	3	3	3	5	31
Land cover	0.33	1	2	2	2	2	3	20
Soil depth	0.33	0.5	1	1	1	1	3	11
Soil drainage	0.33	0.5	1	1	1	1	3	11
Soil texture	0.33	0.5	1	1	1	1	3	11
Soil type	0.33	0.5	1	1	1	1	3	10
Distance	0.2	0.33	0.33	0.33	0.33	0.33	1	6

So the seven stated above parameters were weighted in table 3 and the suitability of the land was done using the weight given to each parameters.

3.10. Irrigation Potential of Birbir River Watershed

Irrigation potentil of Birbir river is an area of land that can be irrigated by the Birbir river. Irrigation potential of the Birbir river watershed was obtained by comparing monthly gross irrigation requirements of the identified land suitable for surface irrigation and the available mean monthly 80% dependable flows in the river catchments based on the method suggested by [12].

4. Results and Discussions

4.1. Irrigation Suitability Analysis

4.1.1. Slope Suitability

The slope suitability analysis revealed that 27.91% (174,359 ha) of the total area of the Birbir watershed was in the range of highly suitable (S1) for surface irrigation with respect to slope. This slope analysis result indicated that about 27.91% (174,359 ha) of the study area was covered with less than 2% slope class and 174,359 ha of the river watershed can be irrigated without any limitations with respect to slope suitability. Similarly 25.35% (158,418 ha) and 41.14% (257004 ha) of the watershed was found to be in the range of moderately suitable (S2) and marginally suitable (S3) for surface irrigation system respectively. This analysis indicated that about 25.35% of the study area was covered with less than 5% slope class and 41.14% of the study area was covered with less than 8% slope class. This result revealed that 158,418 ha of the watershed can be irrigated with some limitations with respect to slope (with some sort of land leveling) and 257004 ha of the watershed have undulating slope and it can be obstacle for water movement by surface irrigation. However, by guiding the water movement manually it can be irrigated with some limitations. The remaining 5.60% (34988 ha) of the total area of the Birbir river watershed was found to be marginally not suitable (N) with respect to slope. According to [24], Soil on steep slopes, are exposed to a high degree of erosion, which is responsible for the further decrease in soil depth. Due to this, 34988 ha of the Birbir river watershed, which has slope greater than 8% (steep slope) is not suitable for surface irrigation. According to [12], the main capital investment on surface irrigation system is mainly associated with land grading, but if the topography is not too undulating, these costs are not high. Hence, surface irrigation development requires favorable topography and information on land and water resources for proper planning. Therefore, from figure 2 it is possible to conclude that, more than half of Birbir river watershed was found to be highly suitable to moderately suitable for surface irrigation in terms of its work efficiency and cost for land leveling, canal construction and cost for pumping system. The researcher reached on this conclusion, because for surface irrigation, the work efficiency is high for flat areas than undulating slopes and cost for land leveling, cost of canal construction and cost for pumping system are less for flat slopes than sleepy (undulating) slopes.

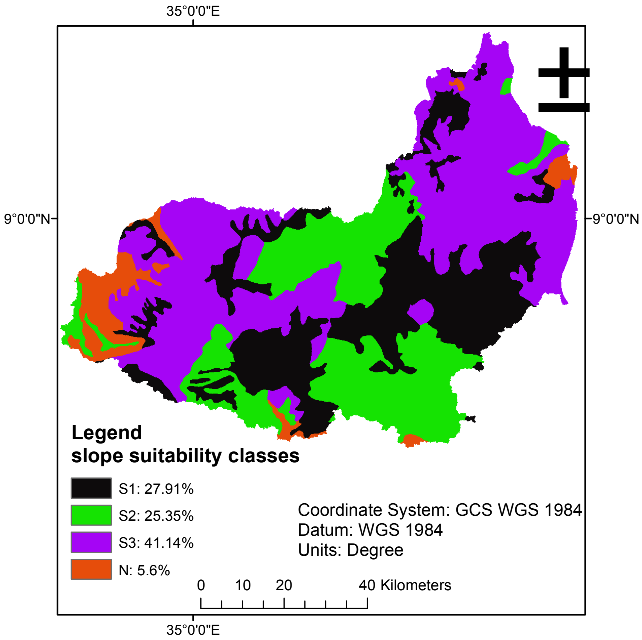

Figure 2. *Reclassified slope suitability map.*

4.1.2. Land Cover Land Use Suitability

The reclassified suitability classes of land use land cover of the watershed for the surface irrigation system are shown in figure 3. From figure 3, 31.21% (198,033 ha) of the total area of the Birbir watershed was found to be in the range of highly suitable (S1) for surface irrigation system with respect to land use land cover of the watershed. This result showed that almost 198,033 ha of the watershed can be irrigated without any limitations with respect to land use and land cover. But only 0.16% (10,50 ha) of the total area of the Birbir watershed was found to be in the range of moderately suitable (S2) for surface irrigation system with respect to land use land cover and this result revealed that the areal coverage of moderately suitable classes such as closed shrub and bare soil are insignificant in the area, were as the remaining 45.33% (287587 ha) and 23.28% (147744 ha) of the total area of the Birbir watershed were found to be in the range of marginally suitable (S3) for surface irrigation system and marginally not suitable (N) with respect to the impact of irrigation on the environment respectively. This result revealed that almost one fourth of the watershed cannot be put under surface irrigation due to the impact of surface irrigation on the environment and costs to remove or change the land for cultivation. However, 287,587 ha of the Birbir watershed can be put under irrigation with some limitations which may cost the some mitigation of the environment with respect to land use and land cover.

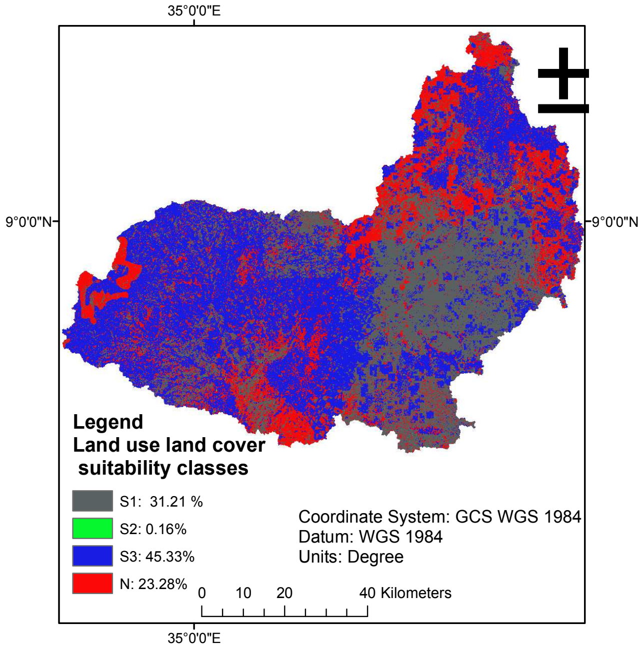

Figure 3. *Reclassified LULC map of the study area.*

4.1.3. Soil Texture Suitability

The results in figure 4 showed that 55.04% (345,523 ha) of the total area of the Birbir watershed was found to be in the range of highly suitable (S1) for surface irrigation system with respect to soil texture suitability of the watershed. This result revealed that almost more than half of the watershed can be irrigated without any limitations with respect to the soil texture suitability. About 17.75% (111,184 ha) of the total area of the watershed was found to be in the range of moderately suitable (S2) for surface irrigation system with respect to the soil texture suitability and this result indicated that the areal coverage of moderately suitable classes such as silt and silt loam was found to be small when compared with S1 and S3. The remaining 27.25% (171048 ha) of the total area of the Birbir river watershed was found to be in the range of marginally suitable (S3) for surface irrigation system with respect soil texture suitability.

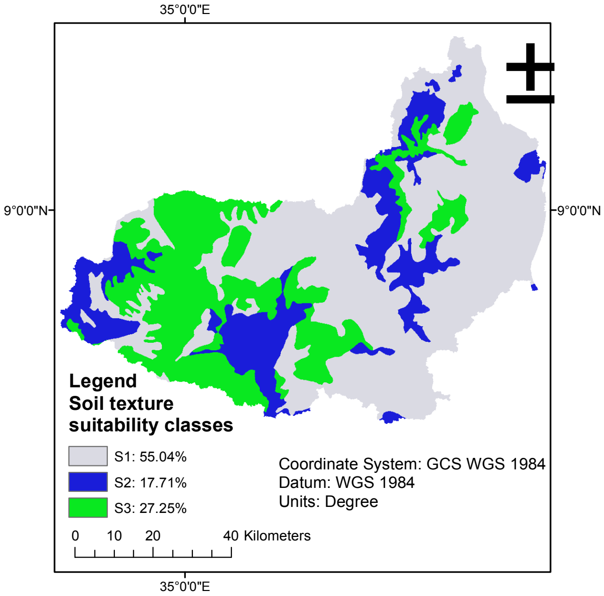

Figure 4. *Reclassified soil texture suitability map of the watershed.*

4.1.4. Soil Depth Suitability

The soils identified in the study area were found to be deep to very deep which was ranging from 90 cm to even greater than 120 cm. the study area has only two ranges of soil depth (90cm and 120cm). Based on the [22] guideline of soil depth suitability evaluation, A soil depth class which is greater than 100 cm was classified as highly suitable (S1), Whereas soil depth of 80 cm to 100cm was classified as moderately suitable (S2). Because of this, soil depth with 120cm is greater than 100cm and it was classified as highly suitable (S1), whereas soil depth with 90cm fall in the range of 80cm-100cm and it was classified as moderately suitable (S2). The result in figure 5 showed, highly suitable (S1) class on the map which is (88.14%) almost covered all area of watershed except small area of the lower part (11.86%), which is the part of moderately suitable class (S2). This indicated that there were no soil depth classes which are categorized under marginally suitable (S3) and not marginally suitable (N) in the watershed. Thus, generally effective soil depths of these soils in terms of depth would not be a limiting factor for crop production.

4.1.5. Soil Drainage Suitability

The study area has only three ranges of soil drainage. These are well drainage, moderate drainage and poor drainage. Based on the [19] guideline of land suitability evaluation, A soil drainage class with well drainage was classified as highly suitable (S1), whereas moderate drainage and poor drainage were classified as S2 (moderately suitable) and N (marginally not suitable) respectively. The result in figure 6 showed highly suitable (S1) class covered 58.01% (364044 ha) of the total area and the area is located at the middle and lower part of the watershed. This result indicated that almost more than half of the watershed can be irrigated without any limitations with respect to the soil drainage suitability. About 25.77% (161,737 ha) of the total area of the watershed was found to be in the range of moderately suitable (S2) for surface irrigation system with respect to the soil drainage suitability and this result indicated that the areal coverage of moderately suitable classes with moderate drainage was found to be one fourth of total area. The remaining 16.22% (101874 ha) was classified as N (moderately not suitable class) for surface irrigation. The poorly drained soil conditions were resulted from the slow permeability of fine textured clayey soils having hard pans in their horizons. When this parameter is evaluated separately from other parameters it can be concluded that almost more than three fourth of the total area in the watershed can be put under surface irrigation. The location of S1 for drainage and S1 for soil texture is opposite. This indicates that soil with good drainages has no good textures for surface irrigation.

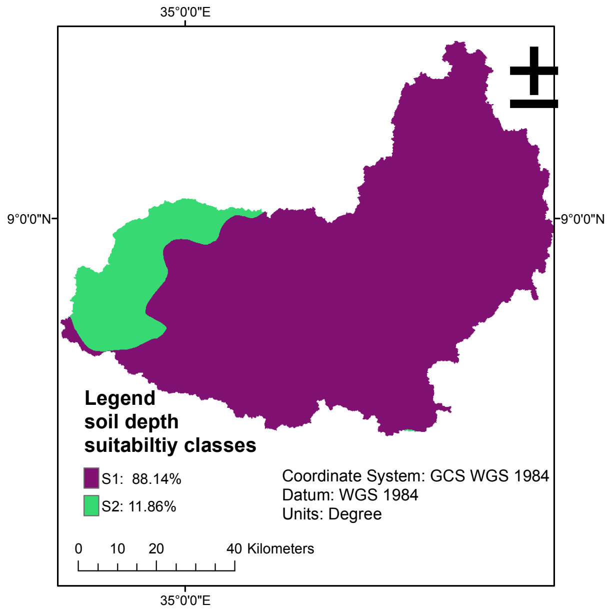

Figure 5. *Reclassified soil depth class map of the study area.*

4.1.6. Soil Type Suitability

Soil types classes such as Chromic cambisols, Humic nitosols, Haplic nitosols and Eutric fluvisols soil were classified as highly suitable (S1), similarly Haplic luvisols, Rhodic nitosols were classified as S2 (moderately suitable) were as soil types such as Chromic luvisols, Haplic lixisols and Eutric gleysols were classified as S3 (marginally suitable) for surface irrigation with limitation factor of their low fertility. As it can be observed from figure 7, 28.57% (179379 ha) of the total area of the Birbir watershed was found to be in the range of highly suitable (S1) for surface irrigation system with respect to soil type suitability of the watershed. This result revealed that almost more than one fourth of the watershed can be irrigated without any limitations with respect to the soil fertility. About 13.20% (82,863 ha) of the total area of the watershed was found to be in the range of moderately suitable (S2) for surface irrigation system with respect to the soil type suitability and this result indicated that the areal coverage of moderately suitable classes was found to be small when compared with S1 and S3. The remaining 53.71% (337,192 ha) of the total area of the Birbir watershed was found to be in the range of marginally suitable (S3) for surface irrigation system which is the largest soil type suitability class. When the soil type is evaluated separately from other parameters, it can be concluded that almost all area in the watershed can be put under surface irrigation by improving the soil textures of the area. However, this improvement may be costly. As it was discussed under soil texture suitability section, the soils textures of the Birbir river watershed were dominated by fine fertile soil texture class such as clay, loam and clay clay loam soil texture. This is a reason why about more than half of the total study area was found to be in the range highly suitable (S1). Generally, all soils types of the Birbir river watershed were found to be suitable for surface irrigation if the limiting factor of productivity and fertility of the land (S2 and S3) is improved and soil and water conservation practices is done.

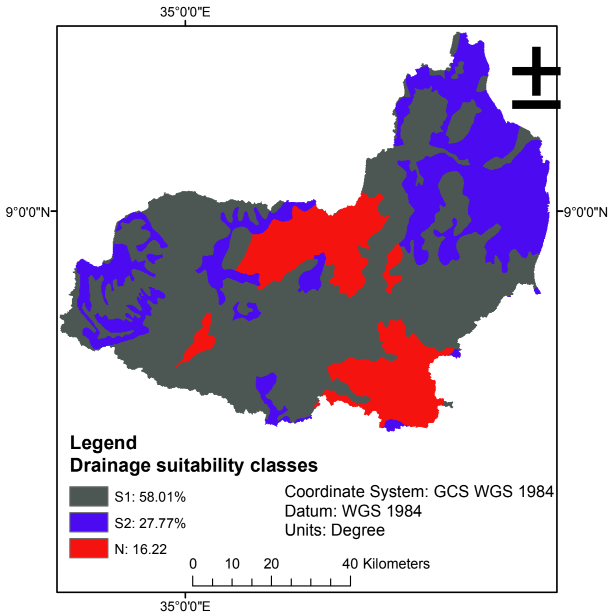

Figure 6. Reclassified soil drainage suitability map.

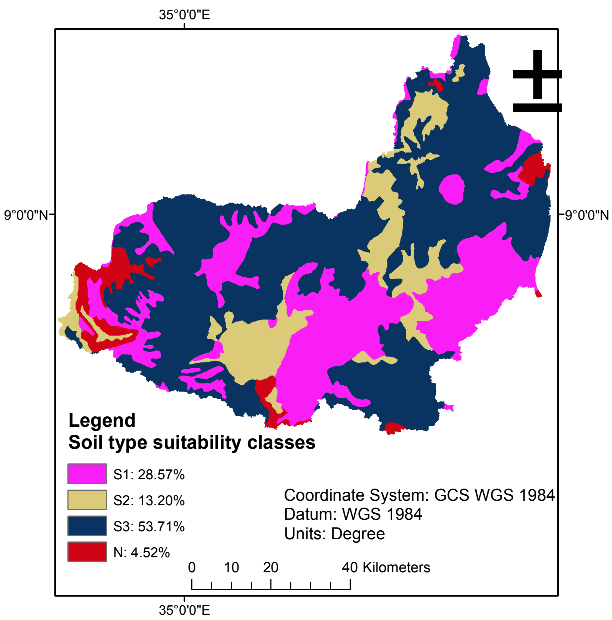

Figure 7. Reclassified soil type suitability map.

4.1.7. Distance from Water Sources Suitability

From the delineated watershed of Birbir River, command area which are closest to the water source Birbir river were classified as high suitable (S1) for surface irrigation and it covers the range of distance from 0.03 km to 10 km. Similarly distance from 10 km to 20 km were classified as S2 (moderately suitable) were as area between 20 km-30 km and greater than 30 km were classified as S3 (marginally suitable) and N (marginally not suitable) for surface irrigation with limitation of their greater distance. According to figure 8, 60.89% (386287 ha) of the total area of the Birbir watershed was found to be in the range of highly suitable (S1) for surface irrigation system with respect to distance from the river. This result revealed that almost more than half of the watershed can be irrigated without any limitations with respect to the limitation of distance suitability. About 29.15% (184915 ha) of the total area of the watershed was found to be in the range of moderately suitable (S2) and this result indicate that the areal coverage of moderately suitable classes was found to be more than quarter. The remaining 6.29% (39873 ha) and 3.67% (23295 ha) of the total area of the Birbir watershed was found to be in the range of marginally suitable (S3) and marginally not suitable (N) for surface irrigation system. Generally, about more than 90% of the Birbir River watersheds were found to be suitable for surface irrigation even though the cost for application for this surface irrigation increases in the areas of S2 and S3 classes.

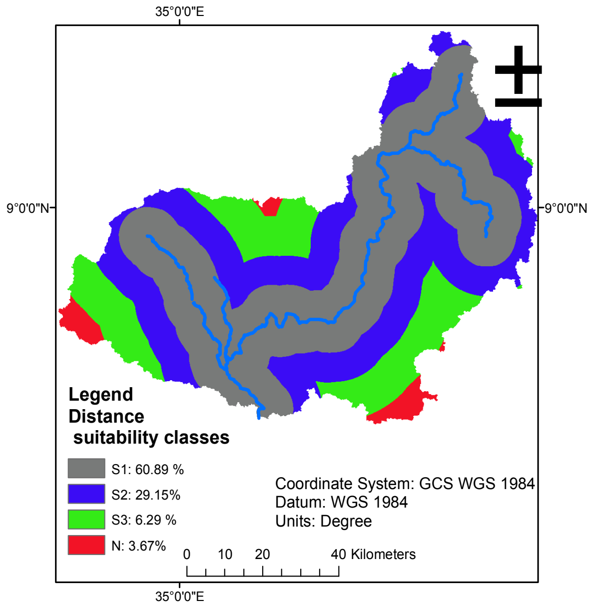

Figure 8. Reclassified distance map of command area.

4.2. Suitable Land for Surface Irrigation

All the seven parameters, which were selected for the evaluation of surface irrigation suitability in the study area, were weighted and areal coverage and their percentage in the watershed were shown in table 4. The results in table 4 showed that 17.03% (106223 ha) of the total area of the Birbir river watershed was found to be in the range of highly suitable (S1) for surface irrigation system with respect to all seven parameters. This result showed that 106,223 ha of the watershed can be irrigated without any limitations with respect to all seven parameters which were considered as a suitability factors for surface irrigation. About two third of the watershed which is 62.92% (392232 ha) was found to be in the range of moderately suitable (S2) for surface irrigation system, were as the remaining 20.05% (124947 ha) of the total area of the Birbir river watershed was found to be in the range of marginally suitable (S3) for surface irrigation system. The total area of the land classified under N class covered was not available. This implies that all lands of the Birbir watershed can be utilized based on the current irrigation technology available.

The result in figure 9 showed that highly suitable (S1) class on the map is located at the upper and middle part of the watershed. From this land suitability location it is possible to conclude that it might be difficult to irrigate all S1 suitable area of the land because enough amount of discharge cannot be accumulated at the middle part of the watershed. However, land suitability in the range of moderately suitable (S2) can get enough discharge than S1 since it is located at lower parts of the river watershed.

Table 4. *Final Suitable surface irrigation land of the study area.*

Suitability class	Area		Suitability class name
	(%)	(ha)	
S1	17.03	106223	Highly suitable
S2	62.92	392232	Moderately suitable
S3	20.05	124947	Marginally suitable
Total	100	623402	

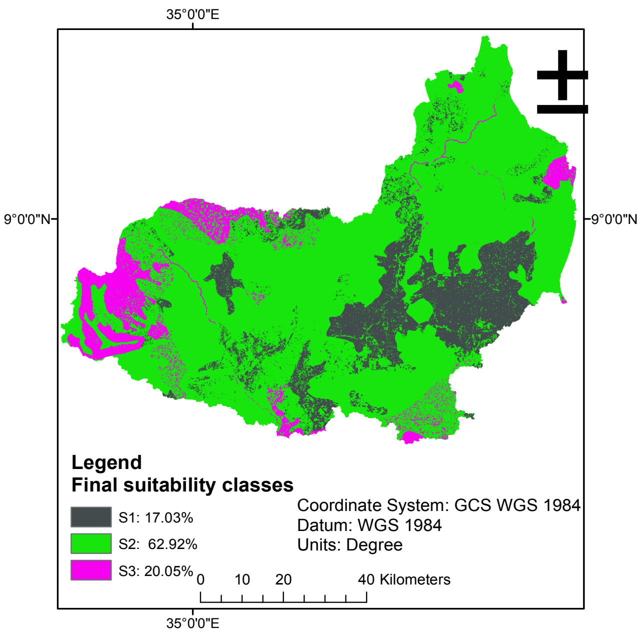

Figure 9. *Final surface irrigation land suitability map.*

4.3. Gross Irrigation Water Requirements

Crop water requirement (CWR), net irrigation requirement (NIWR) and gross irrigation water requirement (GIWR) of each crop were calculated for each months using cropwat software. This calculation was done for the identified five command areas in the watershed. These command areas are; Yubdoo, Caanqaa, Qettoo, Ayiraa, Ouwa and Caanqaa. Accordingly for Yubdoo command area high amount of water is demanded in the month of April which is 45.11 m^3/s, whereas the least water requirement was occurred in the June which is 0 m^3/s. Similarly for Chanqa command area, high amount of irrigation water is demanded in the same month which is 5.88 m^3/s and this value is very small when compared to that of Yubdoo command area. High amount of irrigation water is demanded for Qettoo Chanqa (3.64 m^3/s) and Ouwa Ayiraa (1.02 m^3/s). Generally for all command areas, high amount of irrigation water is required at development stage which is from March to April and 0 m^3/s result revealed that no irrigation water is required in the maturity stage or the small amount of demand during this time is fed by rainfall.

Table 5. *Gross irrigation demand of the two crops and 80% dependable monthly flows.*

Command Area name	Irrigation requirement	Months											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Yubdoo	Total GIR (m^3/s)	0.00	7.31	21.94	45.11	3.66	0.00	0.00	0.00	0.00	7.31	27.26	4.88
	80% Flows (m^3/s)	15.70	16.20	16.90	19.20	27.70	43.10	57.7	62.9	65.5	48.80	28.20	17.30
Chanqa	Total GIR (m^3/s)	0.00	2.73	4.83	5.88	0.21	0.00	0.00	0.00	0.00	2.10	5.25	0.84
	80% Flows (m^3/s)	0.23	0.25	0.07	0.08	0.32	1.02	2.68	4.00	3.35	1.95	0.81	0.43
Qettoo	Total GIR (m^3/s)	0.00	1.69	2.60	3.64	0.13	0.00	0.00	0.00	0.00	1.30	3.25	0.52
Chanqa	80% Flows (m^3/s)	4.04	2.93	2.65	2.35	4.87	14.11	22.97	31.66	34.06	23.73	9.95	6.52
Ouwa	Total GIR (m^3/s)	0.00	0.42	0.80	1.02	0.10	0.00	0.00	0.00	0.00	0.35	0.93	0.19
Ayiraa	80% Flows (m^3/s)	2.44	1.81	1.52	1.48	4.33	9.86	15.46	14.51	16.84	10.04	5.01	3.51

Where: GIR = Gross Irrigation Requirement.

4.4. Irrigation Potential of Birbir River Watershed

The Gross Irrigation Water Requirement (GIWR) of the two crops (maize and potato) and 80% mean monthly dependable flows was compared and the result is shown in the table 5. Table 5 presented the gross irrigation demands of the two crops commonly grown in the Birbir river watershed (maize and potato) and the available 80% mean monthly dependable flows of the corresponding river watershed. Accordingly, the table 5 showed that monthly GIWR of the two crops in the two command areas (Qettoo Chanqa and Ouwa Ayiraa) are less than mean monthly 80% flows of the Birbir River in all months. This means all command areas in the Qettoo Chanqa and Ouwa Ayiraa can be irrigated without any deficiency of water throughout the year. Similarly, monthly GIWR of the two crops in the Yubdoo command area is less than mean monthly 80% dependable flows of the river except two months. This means all command areas in the Yubdoo cannot be irrigated. Therefore, in order to avoid the deficiency of water in this area, the command area has to be reduced or simple temporarily storage structures must be provided. Generally, when GIWR and 80% available dependable flow of the river was compared, the potential irrigable land that can be irrigated without provision of storage structures was found to be around 68,000 ha from the total of 106,223 ha suitable land for surface irrigation.

5. Conclusion

By weighting the values of the seven parameters data sets using weighted overlay in ArcGIS 10.3, the irrigation suitability map was developed and 17.03% (106,223 ha) of the total area of the Birbir river watershed was found to be in the range of highly suitable (S1) for surface irrigation system with respect to all seven parameters. About two third of the watershed which is 62.92% (392232 ha) was found to be in the range of moderately suitable (S2) for surface irrigation system, were as the remaining 20.05% (124947 ha) of the total area of the Birbir river watershed was found to be in the range of marginally suitable (S3) for surface irrigation system. The annual total gross irrigation water requirement for maize and potato were found to be 56.11 m^3/s and 102.46 m^3/s respectively. The GIWR of potato is almost twice of maize and this much difference is happened because of the season in which they are cultivated and their individual crop water requirements. In Chanqa command area, the available river flow capacity was exceeded by the total GIWR of the two crops during the low flows periods. Therefore, in order to avoid the scarcity of water in this command area, the command area (area selected for irrigation) must be reduced or storage structures need be constructed across the Birbir river. Generally, As GIWR and 80% available flow were compered, the potential irrigable land that can be irrigated without provision of any storage structures was found to be around 68,000 ha from the total of 106223 ha suitable land for surface irrigation.

6. Recommendations

Result of the irrigation suitability analysis indicated that, from the total area of the watershed, only 17% (106,223 ha) of the watershed is highly suitable for surface irrigation. Therefore, in order to increase the suitable irrigable land, suitability analysis for other methods of irrigation such as sprinkler and drip irrigation should be carried out. In this study, the surface irrigation land suitability and estimation of water potential was carried out by considering only distance, soil type, soil texture, soil drainage, soil depth, slope, and land cover/use factors. However, there might be effects of other factors such as water quality, environmental impacts, ground water resource, and social terms should also be assessed to get sound and reliable result. The estimation of gross irrigation water requirement of identified command areas was carried out by selecting only two crops based on their current demand in the area. But the future research should select several crops, which has economic value in the market. During the study the researcher had tried to refer different literatures on the Birbir river watershed. However, the researcher couldn’t find researches conducted on the Birbir river especially on irrigation potential of the river. This research entitled as irrigation potential is the first study on this river and the researcher recommend other researchers to conduct different water resource researches on this river.

Acknowledgements

First and foremost, thanks to the Almighty God for granting us with his limitless care, love and blessings all along the way. We grateful to National Metrological Service Agency (NMSA), Ministry of Water, Electricity and Energy, Hydrology Department and Ethiopian Map Agency for providing the required data for this study. Besides, our deep hearted gratitude goes to Jimma Institute of Technology, School of graduate studies for the invaluable knowledge and guidance for our study.

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