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Land Suitability Assessment of Surface Irrigation Potential in Gilgel Gibe, Omo Gibe Basin, Ethiopia

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Abstract

The aim of this study was to assess land suitability for irrigation potential of the Gilgel Gibe I watershed, Oromia Region, Ethiopia. The input data used to process the model and to achieve the objective of the study were soil, digital elevation model (DEM), streamflow, land use land cover. To identify potential irrigation land, irrigation suitability factors such as soil (type, texture, depth, and drainage), slope, land cover land use and distance from water supply were taken into account. Irrigation suitability of each physical land parameters was classified based on the FAO guideline for land evaluation into S1 (highly suitable), S2 (moderately suitable), S3 (marginally suitable) and N (not suitable) suitability classes. The final potentially irrigable land was identified by weighting all the factors of suitability. Result of suitability of land evaluation ratings based on the qualitative land suitability for irrigation indicated that, 26.80% (110578.05ha) are highly suitable (S1), 24.83% (102423.81ha) are moderately suitable (S2), 15.53% (64051.44ha) marginally suitable (S3) and 32.84% (135509.58ha) are not suitable (N) for surface irrigation systems.

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1. INTRODUCTION

Irrigation is one means by which agricultural production can be increased to meet the growing food demands of the fast-growing population of the country. The Irrigation represents an alteration of the natural conditions of the landscape by extracting water from an available source, adding water to fields where there was none or little before, and introducing man-made structures and features to extract, transfer and dispose of water [1, 2]. Land suitability assessment is a land evaluation which usually conducted to determine specific land use for a particular location and identify limiting factors for a particular crop production [3]. The Ethiopian highlands are comprised of land resources which are potentially suitable for irrigation. The country is endowed with ample water resources with 12 river basins with an annual runoff volume of 124.5 billion m^3 of water and an estimated 2.86 billion m^3 of groundwater potential. Ethiopia is considered to be the water tower of Africa [4, 5].

The suitability of the land must also be evaluated on the condition that water can be supplied to it. For many countries, the only solution, therefore, is to manage the available land and water resources in the country in an efficient and sustainable manner. Ethiopia has a significant irrigation potential identified from both available land and water resources. Most of the population in Ethiopia lives in highland areas, with 85% being rural and dependent on agriculture with a low level of productivity [6, 7]. Land suitability analysis Irrigation potential assessment such soil, land cover land use, land slope and distance between water supply and suitable command area should be weighted and evaluated by the use of GIS according to their suitability for irrigation. The suitability of these factors for surface irrigation method and for the given land utilization types can be expressed corresponding to the following suitability classes [8-10]: S1 (highly suitable); S2 (moderately suitable); S3 (marginally suitable) and N (Not suitable).

Land suitability assessment, land use planning and lacking of clearly, current land use and irrigation land suitability description for potential natural resource in the area. Omo Gibe is one of the twelve river basins of Ethiopia with a potential for satisfying the demand of existing and proposed projects on the basin and downstream water users. The study was carried out using ArcGIS as a tool for land suitability assessment of surface irrigation potential and mapping of the assessment result in the context of surface irrigation potential identification of the Gilgel Gibe catchment.

2. Description of the Study area

The Omo-Gibe basin is one of the major river basins in Ethiopia and is situated in the south

western part of the country covering parts of Oromia and Southern Nations, Nationalities and Peoples Region (SNNPR). The Omo Gibe River Basin is almost 79,000 km^2 in area and is situated in the southwestern part of Ethiopia, between 4°30’ and 9°30’ N and 35° and 38° E with an average altitude of 2800 masl. The study area was located on the upstream of the large Omo Gibe basin in the South-Western part of Ethiopia, in Oromia regional state at some 260km from Addis Ababa. Gilgel Gibe lies between $7^0$19′07.15″and $8^0$12′09.49″North latitudes and $36^0$31′42.60″and $37^0$25′16.05″East longitudes with the catchment area of 412563Ha.

3. Material and Methods

The methods used to evaluate land suitability potential surface irrigation was done following the standard FAO guidelines [11], accepted by researchers all over the world [12-14]. The materials and software’s that were used to assess the land suitability for irrigation potential of this study area were:

GPS: GPS provides continuous positioning and timing information, anywhere in the world under any weather conditions.

ArcGIS: which was used for processing and analyzing the database and developing

and executing a map from the database.

Arc SWAT: For Watershed delineation, and develop streams, land use, soil and slope map of the study area in collaboration with ArcGIS.

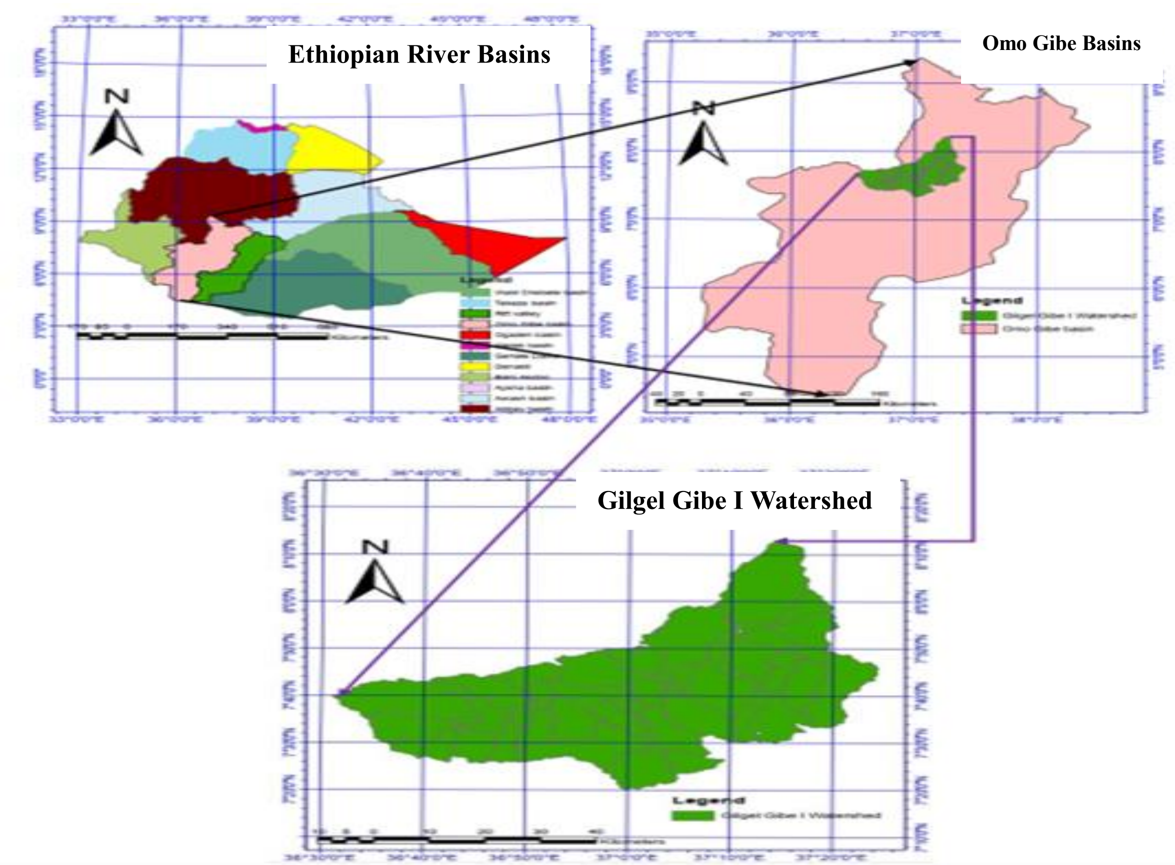

Figure 1: Location of Study area (Ethiopian River Basins, Omo Gibe Basin and Gilgel Gibe I Watershed)

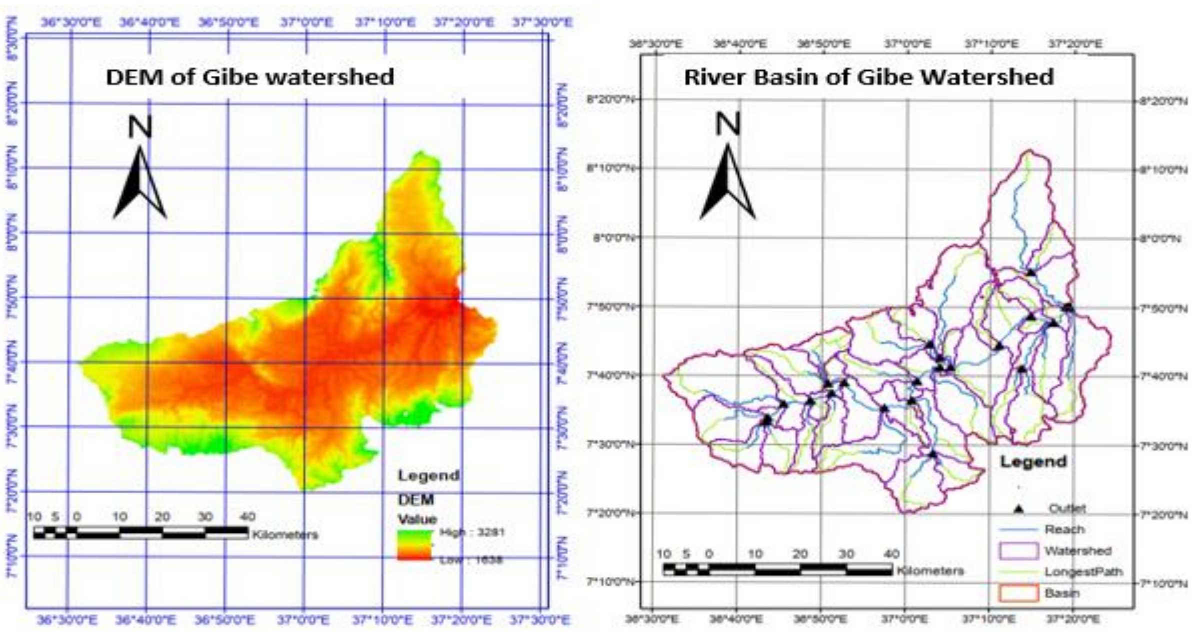

Figure 2. Digital Elevation Model and River basin of Gibe Watershed respectively

3.1. Data Collection

Relevant and appropriate data are very essential prior to the simulation of any model in order to achieve the objective of the research. The required input data for this study were: Digital Elevation Model (DEM), Land use land Cover map, soil map and data, streamflow data. These data's were collected from different sources.

3.1.1. Digital Elevation Model (DEM)

The topography is defined by a DEM that describes the elevation of any point in a given area at a specific spatial resolution and used to calculate Sub-basin parameters such as slope, slope length, and define stream network characteristics such as a channel slope, length and width were all derived from DEM. DEM in the geographic coordinate system was obtained from Ethiopian Ministry of water, Irrigation and Energy bureau GIS Department

3.1.2. Land Use Land Cover Map

LULC is one of the most important factors affecting different processes in the watershed, such as surface runoff, erosion, recharge and evapotranspiration. The LULC data for this study area was obtained from Ethiopian Ministry of water, Irrigation and Energy bureau GIS Department.

3.1.3. Soil Map and data

Hydrological soil type classification considers the physical properties of soils including texture, depth, drainage, and soil structure. Soil data were obtained from the Ethiopian Ministry of Water, Irrigation and Energy.

3.1.4. Stream Flow data

Daily streamflow data was obtained from Ethiopian Ministry of water, Irrigation and Energy bureau hydrology Department. The streamflow data was used to assess water resources potential of the sites for irrigation purpose.

3.2. Data processing and analysis

After all the necessary data were collected from different data sources, further analysis was carried out for each physical land suitability factors to evaluate the suitability of the suggested land for irrigation potential. The suitability of each factor was analyzed and finally weighted to get potential land suitable for irrigation sites.

3.3. Watershed delineation

The geographic information system interface Arc SWAT was used for the setup and parameterization of the model. A DEM had a Geographic coordinate system so it was converted into the projected coordinate system by using Arc toolbox Data management tool. After sub-setting the DEM data, it was imported in the SWAT project and the watershed was delineated as shown in figure 2.

3.4. Identification of potential suitable land for irrigation

Identification of suitable land sites for irrigation was carried out by considering the slope, soil, land cover land use and distance water supply as factors. The individual suitability of each factors was first analyzed and finally weighted to get potentially suitable land for irrigation sites. Once their individual suitability was assessed, the irrigation suitability factors such as slope factor, soil factor (depth, texture, and drainage), land use land cover factor and distance factor were used as the input for irrigation suitability model to find the most suitable land for surface irrigation[8, 11].

3.4.1. Slope suitability analysis

To derive the slope suitability map of the study area, the digital elevation model of the area was used with 30 m resolution of the river basin. Then slope map of sub-catchment was derived using the "Spatial Analysis Slope" tool in ArcGIS 10.3. The Slope derived from the DEM was classified based on the classification system of [15] using the "Reclassification" tool, which is an attribute generalization technique in ArcGIS 10.3. The four suitability ranges S1 (highly suitable, S2 (moderately suitable), S3 (marginally suitable), and N (not suitable) were classified for surface irrigation as shown in Table 1.

Table 1: Area distribution of slope classes of the study area

No.	Slope Classes	Factor rating	Area (Ha)	Area (%)
1	0 - 2	S1	92928.87	22.52
2	2 - 5	S2	81631.98	19.79
3	5 - 8	S3	51350.94	12.45
4	>8	N	186651.09	45.24
Total			**412562.88**	**100**

3.4.2. Soil suitability analysis

Soil is an important determining factor for land suitability assessment for surface irrigation development. The physical properties of the soil preparing soil feature layers of each physical soil parameters; soil texture, soil drainage, and soil depth then the feature layers were converted into raster layer using conversion tool "To Raster". Finally, soil suitability map of each soil physical parameter was developed with the factor rating of S1, S2, S3, and N through reclassified the raster layers based on the [8] soil classification guideline.

3.4.2.1. Soil Depth

The depth of soil that can be effectively exploited by plant roots is an important criterion in the selection of land for irrigation. A soil depth variation from place to place determines the growth of plants and also affects the growth of plant roots. The thickness of the soil materials, which give structural support, nutrients, and water for crops, is referred to as soil depth.

3.4.2.2. Soil texture

Soil texture is another important property as it determines pore spaces of that soil which influence the soil permeability and infiltration rate. Generally, the soil texture of the specified land use is divided into Coarse, medium and fine textural groups based on the FAO guidelines.

3.4.2.3. Soil drainage

Soil drainage refers to the flow of water through the soil, and the frequency and duration of periods when the soil is free of saturation under natural conditions. Soil drainage condition is important as it controls the continuous movement of water and salt through the soil profile.

Table 2: Area distribution of different soil type of study area

No.	Soil Type	Area (Ha)	Area (Ha)
1	Chromic vertisols	91363.41	22.15
2	Dystric fluvisols	71728.2	17.39
3	Dystric nitosols	126819.18	30.72
4	Eutric cambisols	91108.62	22.08
5	Eutric fluvisols	30306.87	7.35
6	Eutric nitosols	4.95	0.01
7	Orthic acrisols	1231.65	0.3
Total		**412562.88**	**100**

3.4.3. Land use land cover suitability analysis

Land use land cover influences on the cost of crop suitability and irrigation practice to prepare the land for agriculture. Land suitability assessment in terms of land use land cover, when the main theme is to give water for agriculturally able land by surface irrigation for better performance. In order to estimate potentially irrigable land, land use land cover classification was done using land use land cover data obtained from the MoWIE.

3.4.4 Distance from water supply (source)

To identify suitable land for irrigation land close to the water supply (rivers), straight-line (Euclidean) distance from watershed outlets was calculated using DEM (30 m) and reclassified. Available irrigable land close to the water supply was identified by creating Euclidean distance along the river to a specified distance using the buffer icon in the analysis tool and clip to the specified study area.

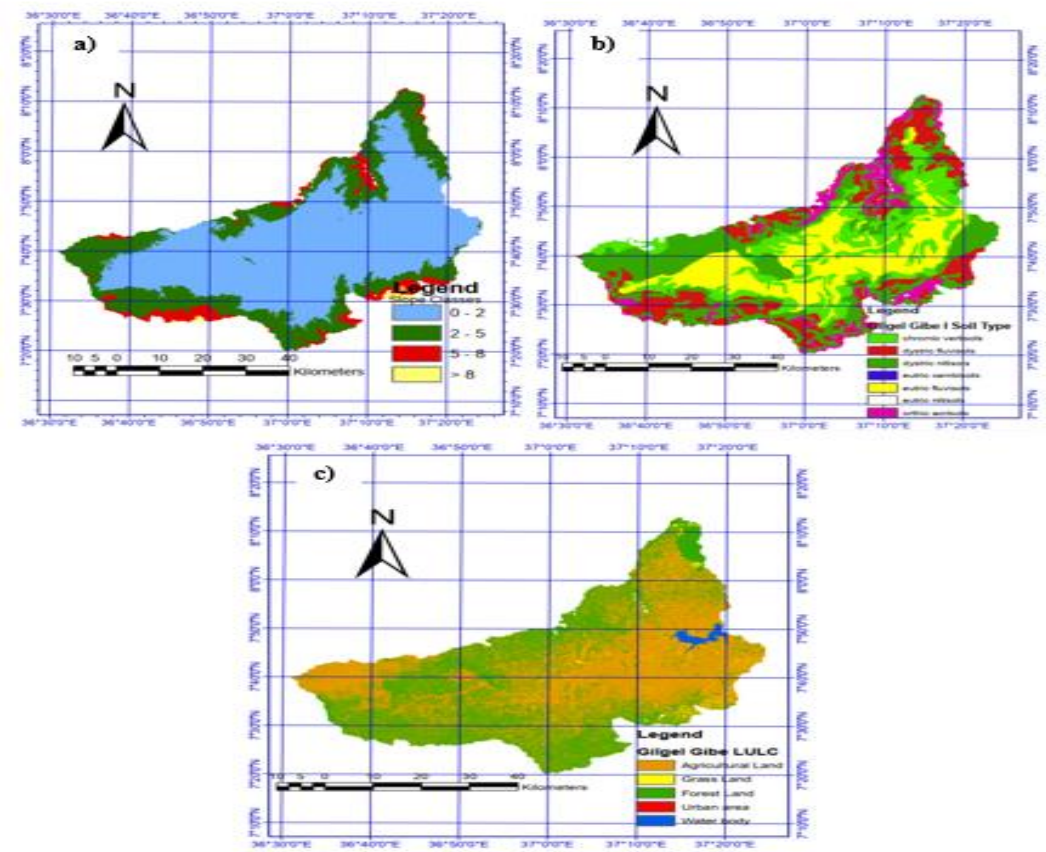

Figure 3. **a)** Slope map of the study area (in %). **b)** The soil type of the study area. **c)** Land use/land cover type of the study area

3.4.5 Weighing of irrigation suitability factors

To find the suitable land site for potential irrigation, a suitability model was created using a model builder in Arc tools box and tools from spatial analysis toolsets. Then, after their individual suitability was assessed, the irrigation suitability factors which were considered in this study such as slope factor, soil factor, land cover land use factor, and distance factor were used as the input for irrigation suitability model to find the most suitable land for surface irrigation. Generally, after irrigation suitability of each parameter was assessed and their suitability map layer of each criteria was developed separately, an overlay analysis was done to generate one suitability map using "model builder" in Arc tools box and tools from spatial analysis toolsets.

Table 3. Land suitability classes [8]

Factor rating	Suitability Class	Description
S1	Highly suitable	Land without significant limitations
S2	Moderately suitable	Land that is clearly suitable but which has limitations
S3	Marginally suitable	Land with limitations so severe that benefits are reduced
N	Not suitable	Land that cannot support the land use on a suitable basis

Table 4. Area distribution of different land use/land cover of the study area

No.	Land use/ Land Cover	Area (Ha)	Area (%)
1	Agricultural Land	229491.9	55.63
2	Forest Area	163730.52	39.69
3	Grass Land	15545.79	3.76
4	Urban area	152.28	0.04
5	Water Body	3642.39	0.88
Total		412562.88	100

4. RESULTS AND DISCUSSION

4.1. Irrigation Suitability Evaluation

4.1.1. Slope suitability

The suitability of the study area for the development of surface irrigation system was developed based on the four slope classes S1, S2, S3, and N. The result of slope suitability of study area for the surface irrigation system and the area coverage of the suitability classes as shown in Figure 6 a) and Table 5. The slope analysis indicated that 22.52% (92928.87 ha) is highly suitable, 19.79% (81631.98 ha) is moderately suitable, 12.45% (51350.94 ha) marginally suitable and 45.24 (186651.09 ha) is not suitable for surface irrigation systems.

Table 5. Slope suitability range of the study area for irrigation.

No	Slope (%)	Coverage area (Ha)	Coverage area (%)	Suitability Class	Suitability Class Name
1	0 – 2	92928.87	22.52	S1	Highly Suitable
2	2 – 5	81631.98	19.79	S2	Moderately Suitable
3	5 – 8	51350.94	12.45	S3	Marginally Suitable
4	>8	186651.09	45.24	N	Not Suitable
Total		**412562.88**	**100**		

4.1.2. Soil suitability

Suitable soil for potential surface irrigation is obtained by creating weighted overlay analysis which involved all data sets of soil physical properties such as soil depth, soil texture, and soil drainage. The final evaluated Soil suitability for irrigation indicating soil texture, soil depth, and soil drainage after reclassification of suitability analysis indicate that the study area could be generally classified into four suitability classes; S1 (highly suitable), S2 (moderately suitable), S3 (marginally suitable) and N (not suitable).

Soil texture: Based on the FAO guidelines for soil evaluation, the soil texture of the study area was evaluated and classified into clay and clay loam. From the total area of the study, 77.49% of the total area of the watershed had been highly suitable to marginally suitable and the remaining part is not suitable by using the criteria of soil texture.

Soil Drainage: Soil drainage classes of the study area was reclassified into S1, S2, S3 and N suitability classes based on FAO guideline for land evaluation. The results in Figure 4 b) revealed that most of the total area of the study watershed had been highly suitable and moderately suitable for surface irrigation system with respect to soil drainage respectively.

Soil Depth: Soil depth variation from place to place determines the growth of plants and also affects the growth of plant roots. Results from the soil depth reclassification of suitability map of the study area were developed Figure 4 C) with S1, S2, S3, and N suitability classes.

Table 5. Soil texture, Drainage, and Depth suitability range of the study area for irrigation.

No	Texture	Drainage	Depth	Texture		Drainage		Depth		Suitability Class	Suitability Class Name
				Coverage area (Ha)	Coverage area (%)	Coverage area (Ha)	Coverage area (%)	Coverage area (Ha)	Coverage area (%)		
1	Clay, Loam	Well	250	126913.14	30.72	162845.1	39.3	102305.0	24.7	S1	Highly Suitable
2	Clay Loam	Moderate	130	121754.23	29.46	127533.5	31.0	126931.2	30.5	S2	Moderately Suitable
3	Sandy Loam	Poor	90	71373.736	17.31	90864.3	22.1	90896.3	22.2	S3	Marginally Suitable
4	Silty Loam	Very poor	50	92521.779	22.51	31319.9	7.5	92430.4	22.5	N	Not Suitable
Total				**412562.88**	**100.00**	**412562.9**	**100.0**	**412562.9**	**100.0**		

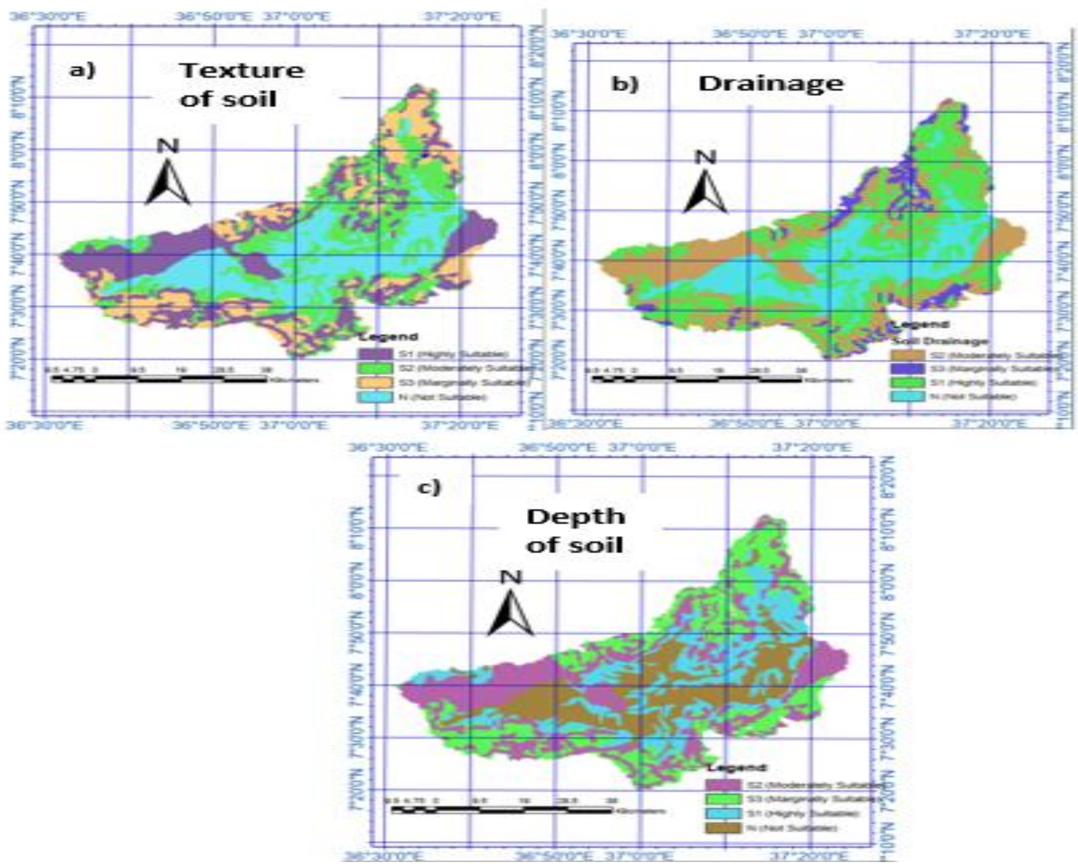

Figure 4. Soil suitability map of the study area. **a)** texture; **b)** drainage; **c)** depth

4.1.3 Land use land cover suitability

Land use land cover has been considered as one of the evaluation parameters in land suitability for irrigation purposes.

The land use type of the study area was reclassified into four suitability classes represents highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and Not Suitable (N). The result of land suitability of study area for the surface irrigation system and the area coverage of the suitability classes as shown in Figure 6 c) and Table 7.

Table 6. Soil type and their suitability class of study area

Table 7. Soil type and their suitability class of study area

No	Soil type	Coverage area (Ha)	Coverage area (%)	Suitability Class	Suitability Class Name
1	Chromic Vertisols	91363.41	22.15	S1	Highly Suitable
2	Dystric Fluvisols	102035.07	24.73	S2	Moderately Suitable
3	Dystric Nitosols	126819.18	30.74	S3	Marginally Suitable
4	Eutric Cambisols	92345.22	22.38	N	Not Suitable
Total		**412562.88**	**100**		

No	Land use/Cover	Coverage area (Ha)	Coverage area (%)	Suitability Class	Suitability Class Name
1	Agricultural Land	229957.83	55.74	S1	Highly Suitable
2	Forest Land	164862.36	39.96	S2	Moderately Suitable
3	Urban Land	13984.2	3.39	S3	Marginally Suitable
4	Water body	3758.49	0.91	N	Not Suitable
Total		**412562.88**	**100**		

4.1.4 Distance from the water supply

Irrigation areas should be located as much as possible close to rivers by considering a buffer zone for the protection of water resources. The suitability of surface irrigation was reclassified into four suitability classes; S1 (highly suitable), S2 (moderately suitable), S3 (marginally suitable) and N (not suitable). The final reclassified result of the distance suitability analysis of the irrigable land was used for weighting overlay for further analysis together with other factors.

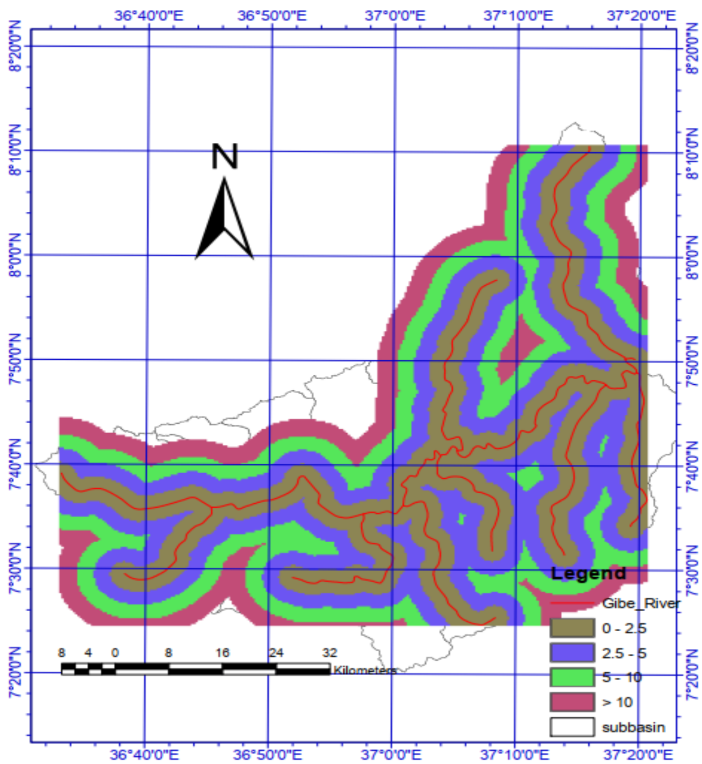

Figure 5. Land use land cover suitability map of the study area.

4.2 Suitable land for Irrigation

The Potential land suitable for irrigation land was obtained by creating irrigation suitability model analysis which involved weighting of values of all data sets such as soil (texture, drainage, and depth), slope, land use land cover and distance from the water supply. Based on FAO suitability classification for surface irrigation guideline the final result of this suitability analysis was identified. From the total coverage of the study area 26.80% (110578.05ha) was classified as high suitable (S1), 24.83% (102423.81ha) moderately suitable (S2), 15.53% (64051.44ha) marginally suitable (S3), whereas 32.84% (135509.58ha) not suitable (N) for surface irrigation.

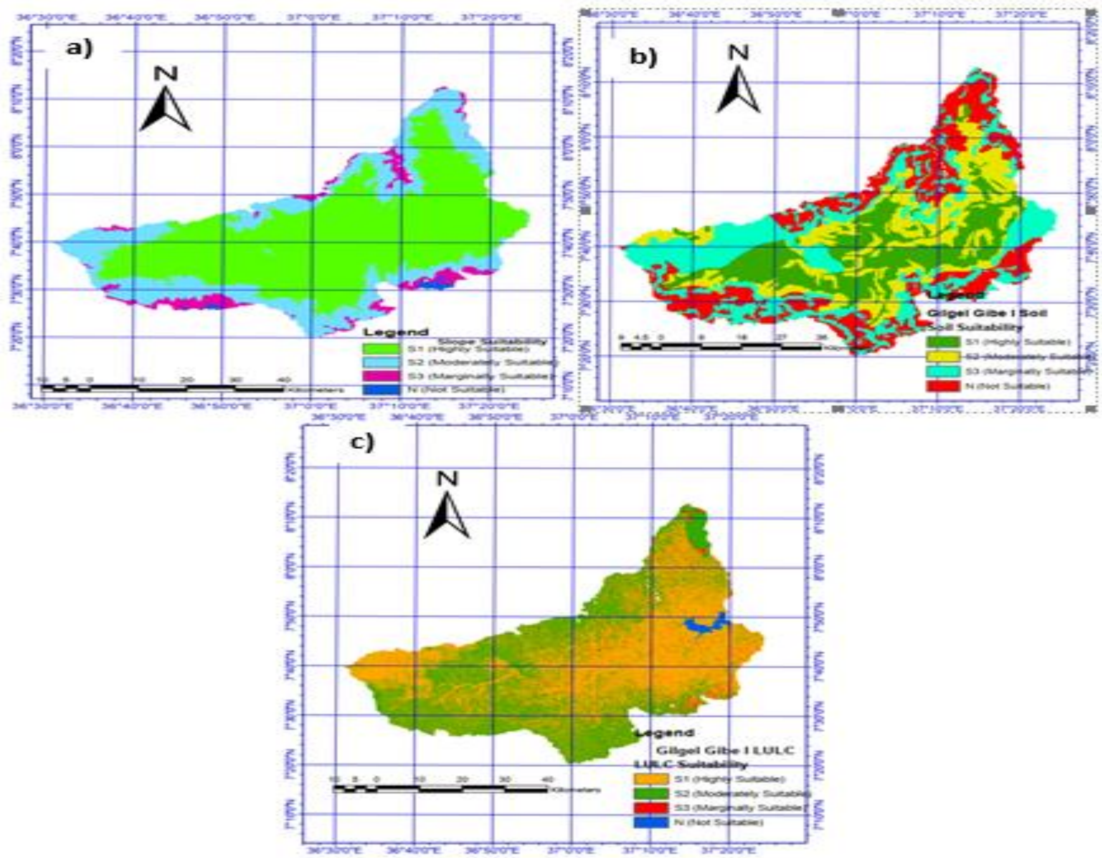

Figure 6. The Summary of suitability classification results. **a)** Slope; **b)** Soil; **c)** Land use land cover

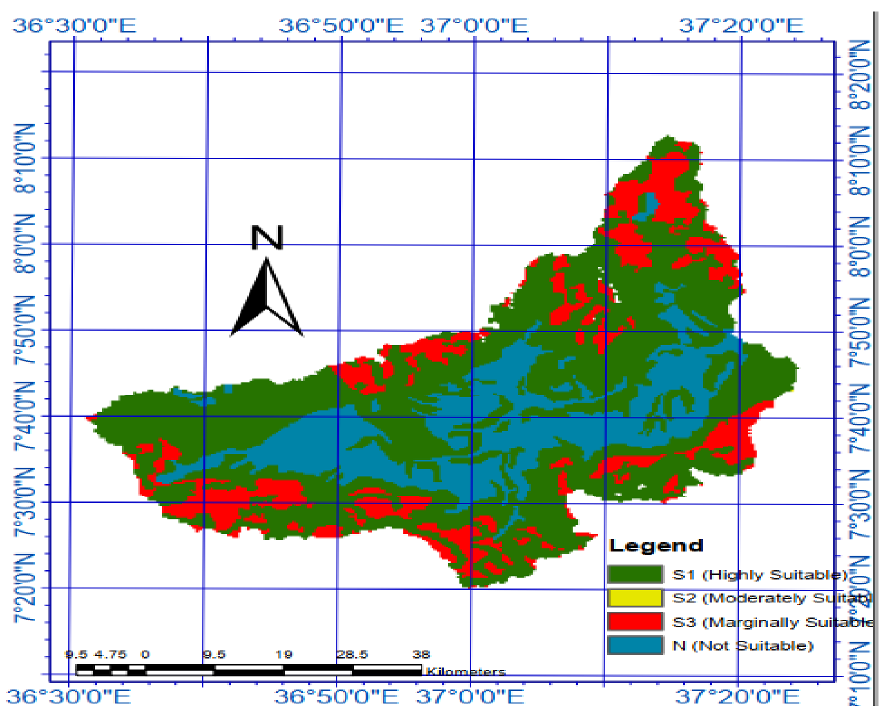

Figure 7. Reclassified factors and final irrigation suitability map of the study area

suitability assessment for irrigation purpose has been

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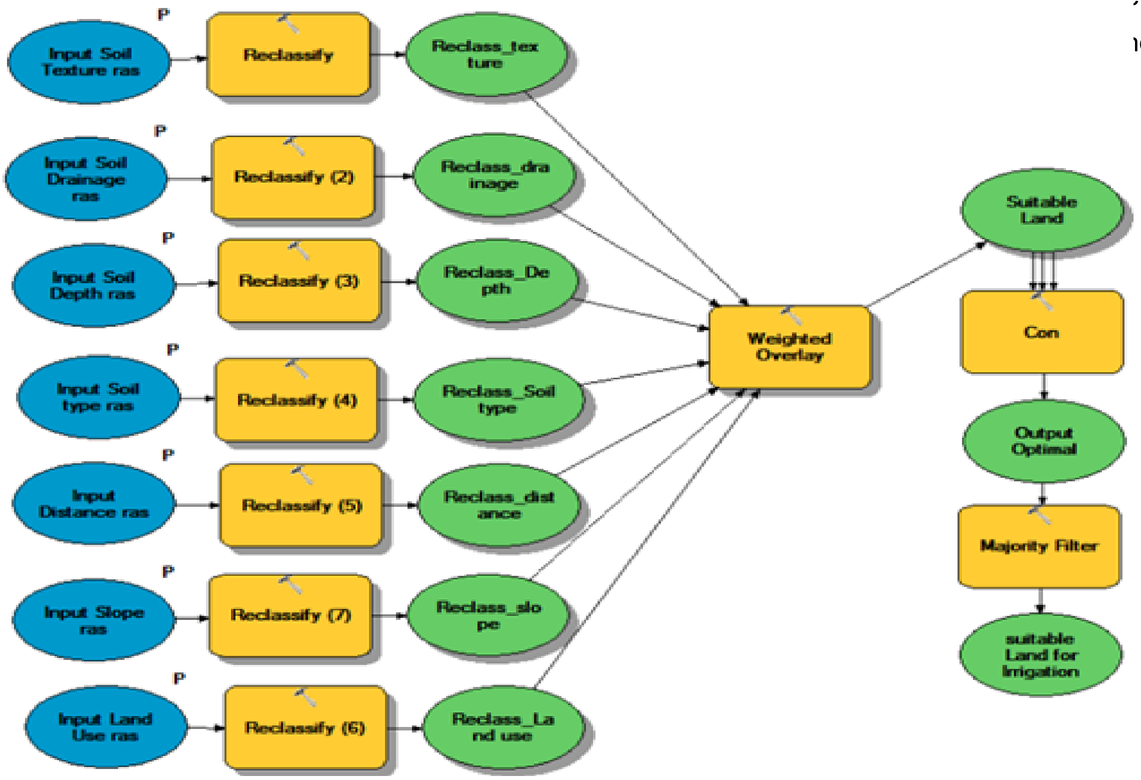

Figure 8. Final Irrigation Suitability Model after overlaying all the suitability factors

Table 8. Final Suitable irrigation land

No	**Area Coverage (Ha)**	**Area Coverage (%)**	**Suitability Classes**
1	110578.05	26.80	Highly Suitable
2	102423.81	24.83	Moderately Suitable
3	64051.44	15.53	Marginally Suitable
4	135509.58	32.84	Not Suitable
Total	**412562.88**	**100**	

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Irrigation development is identified as an important tool to stimulate sustainable economic growth and rural development and is considered as a cornerstone for food security and poverty reduction in the country. Land development planners. Land suitability evaluation highly dependent on specific requirement and expert's knowledge and also requires the involvement of experts, local farmers and decision maker's knowledge.

Suitability study was conducted for the potential irrigation land of Gilgel Gibe watershed, Omo Gibe Basin, Oromia, Ethiopia. The total area coverage of the sub basin that obtained through watershed delineation was **412563** Ha. The main irrigation suitability factors undertaken during the study were slope, soil (soil texture, soil drainage, and soil depth), land use land cover and distance from the water supply. Resulted from the irrigation suitability analysis; **54.76%** of slope**, 77.62%** of soil and **99.09%** land use cover of the study area identified in the range of highly suitable to marginal suitable for irrigation, while **45.24%** of slope, **22.38%** soil, **0.91%** land use land cover of the study area classified as not suitable for irrigation. By weighting values of these constraint data sets using weighted overlay in Arc GIS, the irrigation suitability map was developed and potentially irrigable land for surface irrigation was as 26.80%, 24.83%, 15.53% and 32.84% for S1, S2, S3, and N respectively. Land suitability analysis indicates that only 26.80% of the study area is highly suitable for surface irrigation.

5.2. Recommendations

Irrigation suitability constraints such as water quality, environmental, economic and social terms should be assessed to get sound and reliable result in addition to those parameters (slope, soil, land use land cover and distance from water source) considered in this study to evaluate land suitability for irrigation.

Estimation of irrigation water requirement of identified command area should be carried out by selecting several crops to calculate gross irrigation requirements of identified potential irrigable land among river catchments.

In this paper, only physical characteristics of the parameters are used to analyze the land suitability and capability of the study area. But chemical properties (which vary continuously over the space and it is not possible to model as it is) of the soils are also very necessary for land Capability, crops suitability and irrigation in a specified area. Therefore, research should be conducted on the evaluation of chemical properties of the soil such as Ph., soil fertility, etc. under the study area.

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