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GIS Based Surface Irrigation Suitability Assessment and Development of Map for the Low Land Gilo Sub-Basin of Gambella, Ethiopia

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Abstract
Ethiopia has an important opportunity in water-led development, but it needs to address critical challenges in the planning, design, delivery, and maintenance of its irrigation systems. Gambella has an abundant water and land resources, but due to lack of information related to cultivable and irrigation suitability of the land, its agricultural system does not yet fully productive. This study was initiated to assess the land resources potential of the low land Gilo sub-basin for irrigation and providing geo-referenced map of these resources using Geographic Information System (GIS). By delineating the boundary of the study area, irrigation suitability of each physical land parameters was classified based on the FAO guideline for land evaluation in to S1, S2, S3 and N suitability classes independently, where the final existing and potentially irrigable land was identified by weighting the factors of suitability. The main suitability factors using to identify the existing and potential irrigable land were slope, soil texture, depth, drainage characteristics, soil type and land use/cover. The suitability analysis of the parameters indicates that 89.7% slope, 87.2% soil, 92.9% land use/cover of the study area were classified as potentially suitable for irrigation development in the study area. By weighting analysis of all parameters 9.1% of the study area was found to be existed suitable whereas about 1.3% was restricted for irrigation developments.
Keywords: GIS, land suitability, irrigation, Gilo sub basin, weighted overlay,

1. Introduction

Most of the Ethiopia population lives in highland area, where about 85% being rural and dependent on low input and low output rain-fed agriculture with limited use of irrigation technologies. In addition to directly supports the population's livelihoods, Agriculture is the core driver for Ethiopia's growth. It accounting for over 43% of the country's gross domestic product (GDP) and contributing over 80 % of foreign exchange earnings of the country (IWMI, 2010). The adverse climatic change (a series of droughts) combined with rapid population growth, declining land holding size, growing landlessness, environmental degradation, subsistence and rain-fed dependent agricultural production have resulted in a growing problem of drought vulnerability. This leads to frequent crop failures due to dry spells and droughts which has resulted in a persistent food insecurity often turns into famine with the slightest adverse climatic incident, particularly, affecting the livelihoods of the rural poor of Ethiopia.

In considering the current population growth rate and food insecurity, irrigation development is expected to play an important role in stimulate economic growth and rural development by increasing and stabilizing agricultural production and productivity in Ethiopia (MoWR 2002; MoFED 2006). Improved water management for agriculture has many potential benefits in efforts to reduce vulnerability and improve productivity. In the agricultural development strategy of the country irrigation development is crucial to improve smallholder livelihood through increase their crop production, increase crop variety, and lengthen their agricultural seasons.

Proper use of land depends on the suitability or capability of land and water resources for the development of irrigation facilities could lead to substantial increase in food production in many parts of the country (Fasina, *et al*., 2008). Water-led development opportunity was need to address critical challenges in the planning, design, delivery, and maintenance of irrigation systems. Irrigation planning process requires integrate information about the suitability of the land, climatic conditions and water potential (FAO, 1997). Irrigation water supplies and their requirements are important physical factors in matching the available supply to the requirements. The physical and chemical land qualities that have great contribution on evaluation of land suitability for specific use must also be evaluated on condition that water can be supplied to it. Land evaluation is related with the selection of suitable land, and suitable cropping, irrigation and management alternatives that are physically and financially practicable and economically viable (FAO, 1985).

Although Gambella has an abundant water and land resources, its agricultural system does not yet fully productive. This resulted from no systematic 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.

1.1. Objectives of the study

The main objective of this study is to assess the land resources potential of the Gilo sub-basin for irrigation and providing geo-referenced map of these resources using Geographic Information System (GIS) with the following specific objectives:-

- To provide an integrated, georeferenced spatial database of physical land resource of irrigated agriculture.
- To assess existing and potential land suitability of lowland Gilo sub basin for surface irrigation
- To develop land suitability map of the lowland Gilo sub-basin area for surface irrigation.

2. Methodology of data collection and analysis

2.1. Location

The irrigation suitability study was conducted for lowland Gilo sub basin which located in the lowland Gilo sub basin of Gambella regional state in between the geographical coordinates of $7^0$20'34.8" to $7^0$58'48" N latitude and $33^0$31'12" to $34^0$37'8.4" E longitude. The total area coverage of the sub basin that obtained through watershed delineation is 197,124 ha, of the Goge, Jore and partially Dima administrative woredas. The sub basin is one of the tributary of the Baro Akobo basin.

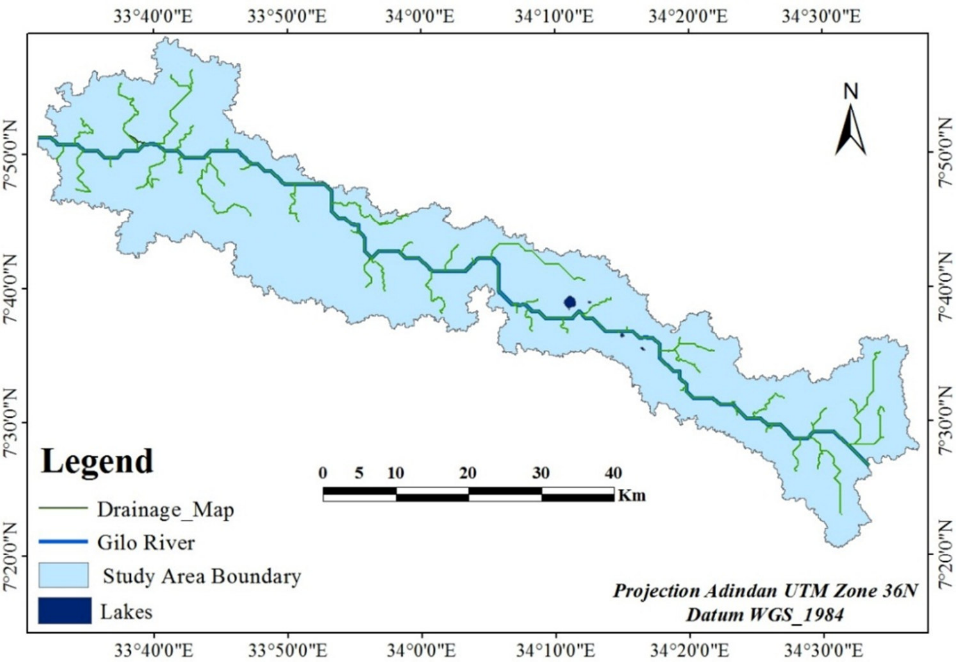

Figure 1. Surface drainage distribution and location map of Lowland Gilo Sub basin

2.2. Data Collection

To achieve the objectives of the study different data inputs were collected from the study area and from different sources such as, SRTM-DEM and Satellite Image from Ethiopian Mapping Agency, Soil data from Oromia Water Works Design & Supervision Enterpris (OWWDS) and GPS reading Point data from the study area. Material used to effectively execute the research were including Global Mapper11, ArcSWAT 8.0, ArcGIS10, ERDAS Imagine 2010.

2.3. Methods

After all the necessary data were collected from different data sources, further analysis were carried out for each physical land suitability factors to evaluate suitability of the suggested land for surface irrigation. The main irrigation suitability factors undertaken during the study were slope, soil texture, soil drainage, soil depth, land use/cover, stoniness and soil type. The suitability of each factors were analyzed and finally weighted to get existing and potential irrigable sites.

2.3.1. Watershed delineation

Watershed of the low land Gilo sub-basin was delineated 30 meter spatial resolution ASTER Digital Elevation Model by imported it to Global Mapper 11 and configured its coordinate system to UTM projection and WGS_1984 datum. The projected DEM was exported to Arc GIS to run automatic watershed delineation using the Arc SWAT.

2.3.2. Slope suitability analysis

Slope map of the specified sub basin was derived from SRTM-DEM of 30 m spatial resolution using the "Spatial Analysis Slope" tool in ArcGIS and it classified based on the classification system of FAO (1999) using the "Reclassification" tool in to suitability classes and Finally slope suitability map was developed and data layers were prepared for further overlay analysis.

2.3.3. Soil suitability classification

To soil suitability of the study area for irrigation was analyze by taking soil physical and chemical properties from the OWWDSE Integrated land use planning of Gilo sub basin (2012),.

Firest preparing soil feature layers of each physical soil parameters; soil texture, soil drainage, soil depth, stoniness and soil type then, the feature layers were converted into raster layer using conversion tool "To Raster". Finally soil suitability map of each soil physical parameter were developed with the factor rating of S1, S2, S3, and N through reclassified the raster layers based on the FAO (1976, 1979 and 1991) soil classification guideline (Table 1).

Table1. Soil suitability factor rating for irrigation suitability

Factors	Factor rating			
	S1	S2	S3	N
Drainage class	Well	Imperfect	Poor	Very poor
Soil depth (cm)	>100	80-100	50-80	<50
Soil texture	L-SiCL, C	SiL, SCL	SL	
Slop (%)	< 2	2 - 5	5 - 8	>8
Salinity	<8 mmhos/cm	8-16 mmhos/cm		
Alkalinity	<15 ESP	15-30 ESP		

Source: FAO guideline for land evaluation, (1976, 1979, 1991 and 1999)

2.3.4. Land use/land cover

Land use/cover classifications were generating through image classification of Landsat ETM+5 satellite imagery of the study area, which was taken by Land sat ETM+5 satellite having 1, 2, 3, 4, 5, and 7 bands and 30 m spatial resolution using ERDAS Imagine 2010 software. To validate and crosscheck the result of the ETM+5 classification with known ground truth data, accuracy assessment was checked for the area of interest (AOI) of the classified images by calculating the error matrix, kappa coefficient in ERDAS software.

2.3.5. Weighing of irrigation suitability factors to find potential irrigable sites

After irrigation suitability of each parameters were assessed and their suitability map layer of each criteria were developed separately, an overlay analysis was done to generate one suitability map using "model builder" in Arc tools box and tools from spatial analysis tool sets. An overlay analysis in Arc GIS.

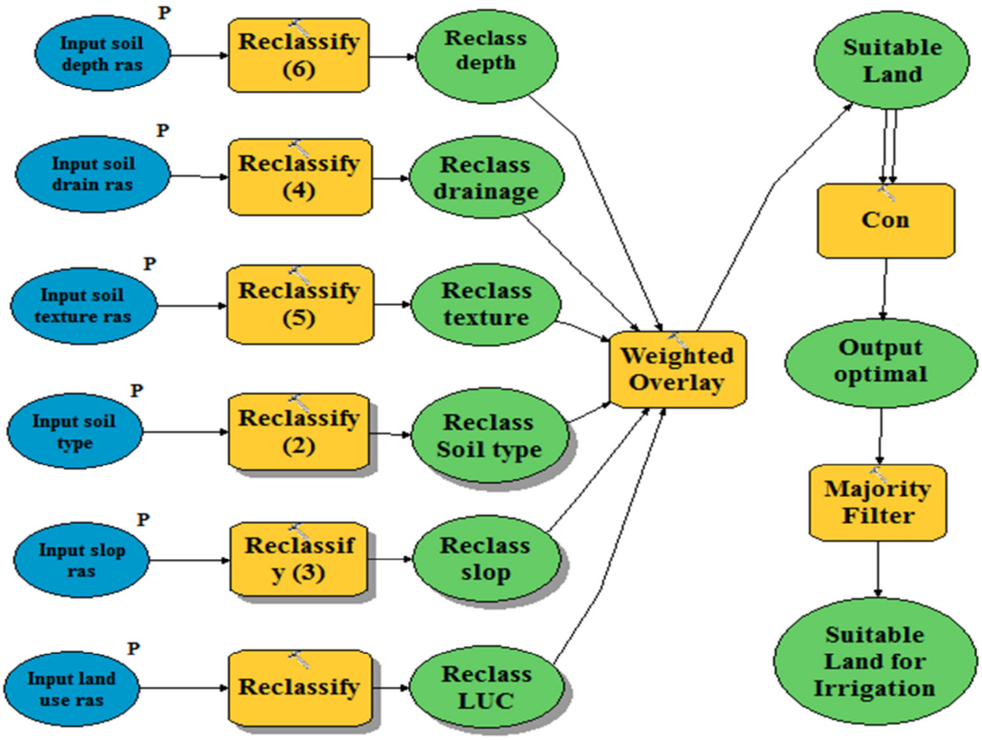

Figure 2. Irrigation suitability model

3. Results and Discussion

3.1. Slope suitability

The slope analysis indicated that about 89.7% of the flat lowland area was classified as highly to marginally suitable for surface irrigation (Figure 4.1). Only 9.5% of the sub-basin area having slope of greater than 8%, which is marginally to permanently not suitable for surface irrigation. According to FAO (1976) suitability classification for surface irrigation, most of the area of the lowland Gilo sub-basin was falls below 8%, which is suitable range of slop classification for surface irrigation with miner modification to negotiate the natural slop.

3.2. Soil suitability analysis

The dominant soil types obserbed on the lowland Gilo sub basin were majorly classified as Luvisols, Vertisols, Planosols and Stagnosols as shown on Figure 3 (1). Luvisols which are fertile and suitable soil for a wide range of agricultural uses are obserbed on the alluvial plains of upper Gog and some part in Dima woredas. they developed on residual colluvial and volcanic basalt parent material and dominanted by Haplic Luvisols, Cutanic Luvisol and Vertic Luvisol. those soils well to moderate soil drainage condition and laid on 2-5% slope range.

vertisols including molic vertisols and stagnic vertisols are the most dominant soil type in the study area. they developed on alluvium parent material. Those soils have considerable agricultural potential, but adapted management is a precondition for sustained production. Mollic Vertisols is located in parts of the Gog, Jore and to some extent in Dima woredaswhere as the Stagnic Vertisols were situated at the lower plain of seasonally flooded area in part of Jor wereda

Vertic planosols and vertic stagnosols with clay to clay loam in soil texture and very deep siol depth are found on seasonally flooded area of Jor woredas. They developed on alluvium parent material. Vertic Planosol have well to moderate soil drainage condition with 0-2% slope range. Vertic Stagnosols which is the most common in flat or gently sloping have very poor soil drainage condition and they distributed on level alluvial plains of less than 5% slope range. The agricultural suitability of Stagnosols is limited because of their oxygen deficiency resulting from stagnating water above a dense subsoil. Therefore, they have to be drained.

With regard to soil texture, it is domineted by fine soil texture class (clay) almost uniform throughout the soil horizons with high retention (moisture holding capacity) and less infiltration rate. It could be related to the uniformity of the landform, slight variation inslope position, dominated by the same parent materials (alluvial deposit) and the fact that soil mineral particles were inherent property of soils not readily subjected to change due to difference in management practices.

The soils identified on flat flood plains, and flat to gently undulating lands (Vertisols, Luvisols and Stagnosols) were deep to very deep in soil depth. It was ranging from 1 meter to even greater than 2 meters. Thus, generally effective soil depths of these soils would not be a limiting factor for crop production through application of irrigation technology.

According to FAO soil permeability evaluation techniques the soil drainage of the flat and alluvial flooded plains of lowland Gilo sub basin was falls under well, moderately well, imperfectly, poorly and very poorly drained conditions (Figure 3.3). The lower part of the study area were dominated by imperfectly to very poorly drained soil drainage condition (Figure 4.4). In relation to agricultural crop production this soil drainage condition is the most limiting factors in most soil types of the study area, which further need special attention to address such problems through improvement of soil drainage

From the field survey, soils of the lower Gilo sub basin which was characterized by flat, undulating to rolling type of land form were almost free from stones. Generally, stones in the soils of the Gilo sub basin were not found to be a limiting factor in relation to mechanization and crop production through irrigation potentials.

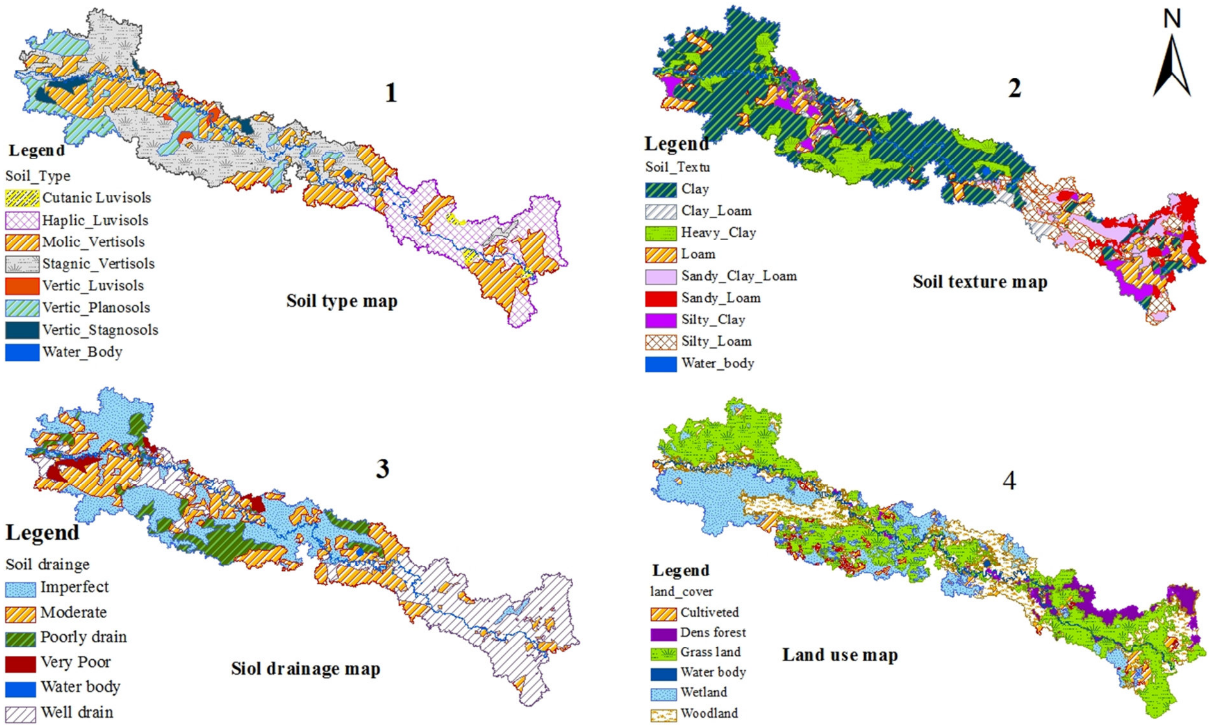

Figure 3. GIS based Irrigation suitability factors distribution map in the study area.

Soil acidity, low organic carbon, low total nitrogen and low available phosphors were limiting soil chemical properties for crop production specialy in Luvisol soil types of the study area. The limitation of those soil chemical properties could causes reduction of agricultural crop productivity. So special improvement practice such as liming of the acidic soils to raise the pH to neutrality, adding animal manure and plant residue to mend the low organic carbon, application of Nitrogen and Phosphors rich fertilizers (UREA and DAP) to alleviate Nitrogen and Phosphors deficiency in the soil.

Table 2. Analysis of soil suitability for irrigation

Soil Type	Area (ha)	Depth (m)	Tex ture	Drainage	Slope (%)	Soil suit	Depth suitab	Textu Suit	Drain. Suit	slop Suit
River and Lake	1640.1	-	-	-	0	-	-	-	-	Water
Haplic Luvisols	8157.4	100	SL	Well	>8	S1	S3	S3	S1	N
Cutanic Luvisols	646.3	150	C	Well	>8	S1	S2	S1	S1	N
Haplic Luvisols	16312.1	120	SiL	Well	2-5	S1	S2	S2	S1	S2
Molic Vertisols	17148.3	200	C	Moderate	2-5	S2	S1	S1	S3	S2
Stagnic Vertisols	2822.0	200	C	Imperfect	2-5	S3	S1	S1	S3	S2
Cutanic Luvisols	416.3	200	C	Moderate	2-5	S1	S1	S1	S2	S2
Haplic Luvisols	3676.9	150	CL	Moderate	<2	S1	S2	S1	S2	S1
Molic Vertisols	21166.5	200	C	Moderate	<2	S2	S1	S1	S2	S1
Stagnic Vertisols	40245.5	200	C	Imperfect	<2	S3	S1	S1	S3	S1
Stagnic Vertisols	21528.3	200	H. C	poor	<2	S3	S1	S2	N	S1
Vertic Luvisols	313.6	200	L	Moderate	<2	S1	S1	S1	S2	S1
Vertic Planosols	13079.1	200	C	Imperfect	<2	S3	S1	S1	S3	S1
Vertic Planosols	5731.4	200	L	Moderate	<2	S3	S1	S1	S2	S1
Vertic Planosols	2850.9	200	SiC	Well	2-5	S3	S1	S1	S1	S2
Vertic Stagnosols	2168.0	200	H. C	Very poor	<2	S3	S1	S2	N	S1
Haplic Luvisols	13849.1	100	S CL	Well	5-8	S1	S3	S2	S1	S3
Molic Vertisols	7020.3	150	SiC	Well	5-8	S1	S2	S1	S1	S3
Molic Vertisols	14772.8	150	L	Well	5-8	S1	S2	S1	S1	S3
Vertic Luvisols	1141.0	200	CL	Moderate	5-8	S2	S1	S1	S2	S3
Vertic Stagnosols	1894.0	200	C	Very Poor	5-8	S3	S1	S1	N	S3
Cutanic Luvisols	550.2	150	C	Moderate	5-8	S1	S2	S1	S2	S3

3.3. Land use/cover evaluation

Seven land use/cover classes; grassland, wetland, woodland, forest area (dense), cultivated land, water body (lake and river) and residences (Figure 3.4), were derived from the Land sat ETM+5 image based on the supervised classification classified with over all accuracy of 87.29% and Kappa coefficient of 0.846, where it indicated the land use/cover classification have a strong agreement according to Rahman *et.al.* (2006).

The lower part of the study area Jor woreda, which is frequently suffers from seasonal water-logging were dominantly covered by open grassland and Wetland (seasonally swampy area). most of the wetland area are consisted of land that was inundated for about 4-5 months in a year and they distributed on the lower plain along the Gilo River where recession farming is practiced on when the wetland area becoming dried out.

Dense forest having ground cover of greater than 50% is obserbed on the apper part of the study area gog woreda. An open wood land is seen scattered throughout the study area in associated with open grassland, wetland and moderately cultivated land uses. scattering cultivation, shifting cultivation and rescission farming of maize, sorghum, groundnut, rice, sesame, tomato, onion and okra crops are the main farming activities obserbed on the study area with limited use of irrigation agriculture.

3.4. Suitable land for irrigation

based on the interperation of pyisical and chemical characterstics of the parameters, the qualitative land evaluation for irrigation suitability implies that majority of the lower part of the study area identified as highly suitable for surface irrigation inrespect to slop, soil depth and soil texture as shown on number 1, 2, 3 of figure 4, where some limitations are obserbed on soil drainage condition (Figure 4.4.).

The final result of irrigation suitability model analysis which involved weighting values of each data sets implies that large portion of the lowland Gilo sub basin was classified under potentially suitable for the application of surface irrigation where about 9.1% (17874.5 ha) of the total area coverage in the study area was found to be existing suitable and only about 1.3% of the area coverage classified as marginaly and permanently not suitable for surface irrigation (Figure 4.7).

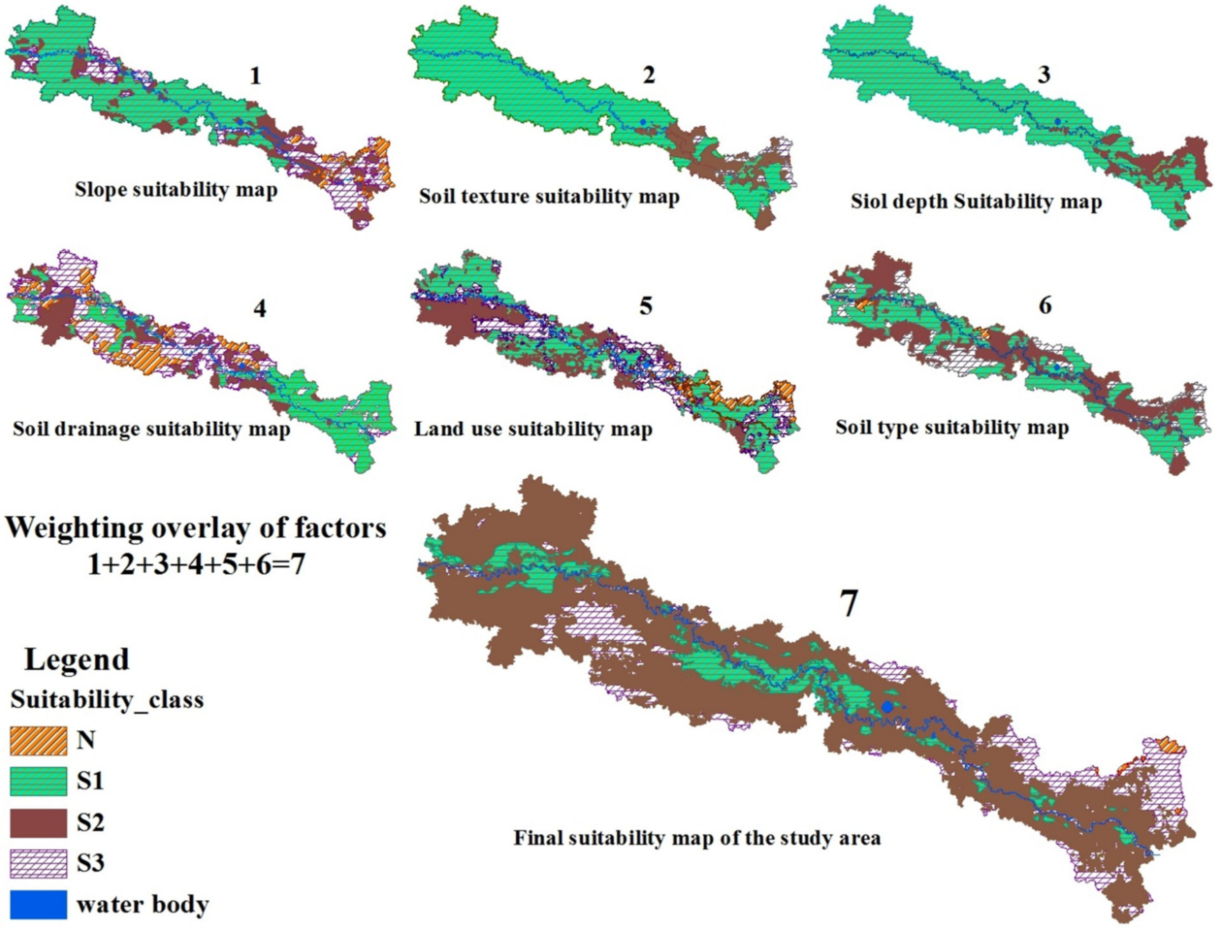

Figure 4. Reclassified factors and final irrigation suitability map of the study area

4. Summary and Conclusion

The irrigation suitability study was conducted for lowland Gilo sub basin which located in the lowland Gilo sub basin of Gambella regional state. The total area coverage of the sub basin that obtained through watershed delineation is 197,124 ha. It had been carried out to evaluate and estimate suitable irrigable land in the study area and develop final suitability map.

The main irrigation suitability factors undertaken during the study were slope, soil texture, soil drainage, stoniness and soil depth, land use/cover and soil type. Resulted from the irrigation suitability analysis; 89.7% of slope, 99% of soil depth 57.6% and 92.9% land use/cover of the study area identified in the range of highly suitable to marginal suitable for surface irrigation. This indicates that most of the lowland Gilo sub-basin was potentially suitable for irrigation development. The soil drainage classification implies that 41.6% of the study area was classified under imperfect to very poor drainage. In relation to application of surface irrigation imperfect soil drainage condition was the most limiting factor which makes most of the soil to classify as S2 and S3. Other soil related irrigation suitability factors like salinity, alkalinity and stoniness are very low to the extent of no negative impact. In terms of land use/cover, 7.1% of the study area including; settlement, dense forest and water body are restricted from irrigation. By weighting values of these constraint data sets using weighted overlay in Arc GIS, the irrigation suitability map was developed and potential irrigable land for surface irrigation was as 9.1%, 73.0%, 15.8% and 1.3% for S1, S2, S3, and N respectively.

From the results obtained the conclusion that could be drawn was, all most all the study area was suitable for surface irrigation development (98% of the total area) with respect to slope, soil depth, texture, salinity, alkalinity, stoniness, and land use/cover. Based on the finding of this study, it was clear that the most limiting factor for irrigation suitability in the study area is soil drainage limitation.

Irrigation investment plays an important role in maintain sustainable food security by improving the agricultural production which is the core foundation for Ethiopia's economy, growth and long-term food security. So the considered recommendations to develop sustainable irrigation investment are;

- Irrigation suitability constraints such as water quality, environmental, economic and social terms should be assessed in addition to those parameters (slope, soil, land use/cover and stoninnes) considered in this study to evaluate land suitability for irrigation.
- GIS is a powerful technology used for systematic land suitability assessment and develop clearly current land use and irrigation land suitability description for potentially resource in the area. So for detail and accurate assessment GIS and remote sensing data inputs should be recent data layers with high spatial resolution.
- Land-use policy must take account of land suitability in relation to the expected future needs and the possibility of meeting demands. The critical importance of land for specified uses should be known either physical or economic suitability.

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