A GIS-Based Multi-Criteria Land Suitability Analysis for Surface Irrigation along the Erer Watershed, Eastern Hararghe Zone, Ethiopia

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Abstract: The high dependency on rain-fed and the incessant erratic rainfall during the main growing seasons in Ethiopia pose a huge threat to agricultural production and productivity. Multi-criteria irrigation land suitability analysis and mapping can play an important role not only in sustainable use of scarce resources, but also in overcoming the global problem of water scarcity and crop production caused due to the high degree of rainfall variability and unreliability. The objective of this study was to determine suitable sites for surface irrigation along the Erer Watershed of East Hararghe Zone, Ethiopia. The study employed GIS-based multi criteria land suitability evaluation method considering fifteen factors , namely, soil pH, soil type, soil drainage, soil depth, AWSC, impermeable layer, ECE, CEC, phase, organic carbon, texture classes, obstacle to root, land use /land cover, slope, and distance from the river outlets to find suitable land for surface irrigation. Each factor was standardized to a common measurement scale so that the results represent numeric range giving higher values to more suitable and lower values to less suitable attributes. Using the Weighted Overlay tool, the values of each dataset were weighted and combined to find the most suitable location for irrigation using the ArcGIS environment. The results of the study revealed that about 386,731ha (11.7% of the watershed area) is highly suitable while 140,308 ha (36.3% of the watershed area) is not suitable for surface irrigation. The remaining suitability classes placed within the marginally and moderately suitable categories were about 151,120 ha (39.07%) and 50,223 ha (12.98%) of the watershed area, respectively. The findings drawn from this study can play an indispensable role in boosting irrigable land and crop production in the study area by considering suitable irrigable lands in terms of the fifteen factors described.

Keywords: GIS; Multi Criteria Evaluation; Surface Irrigation; Weighted Overlay Analysis; Suitability Map

1. Introduction

Ethiopia, one of the mountainous countries in East Africa, is often called the "Water Tower of Africa" due to its topographical nature and climatic condition. The country is endowed with a substantial amount of water sources. It receives about 980 billion cubic meters square of rain water per year. The irrigation potential is estimated to be about 3.7 million hectares, of which only 190,000 hectares (5.3% of the potential) has currently been under irrigation and plays insignificant roles in the country's agricultural production (Negash and Seleshi, 2004). Despite the presence of immense potential for expanding irrigated agriculture in Ethiopia, irrigation systems are little developed and at an infant stage in the country, with very low contributions to the growth of the agriculture sector, which is the backbone of the country's economy (MOA, 2011 and Seleshi, 2010). The country largely depends on rain-fed agriculture which is highly vulnerable to high degree of rainfall variability and unreliability (Hailemariam *et al.,* 2018). This in turn has resulted in frequent crop failures and droughts which negatively affect the agricultural productivity and food supply of the fast-growing population in the country.

The high dependency on rain-fed farming in the dry lands of Ethiopia and the erratic rainfall requires an alternative means to improve agricultural production and productivity. These can be achieved through an optimal development of surface irrigation (FAO, 2003). Surface irrigation is the application of water by gravity flow to the surface of a field either the entire field is flooded (basin irrigation) or the water is fed into small channel (furrow) or strip of land (borders). It is the oldest and still the most widely used method of water application to agricultural lands. Surface irrigation offers numerous benefits for the less skilled and poor farmers. Even if local irrigators have least knowledge of how to operate and maintain the system, more than 90% of the world uses surface irrigation (Saymen, 2005). These systems can be developed at the farm level with a minimal capital investment (Kalkhajeh *et al.,* 2012). Proper land suitability evaluation of land resources in irrigation command area is a prerequisite for better utilization of land resources which help to optimize and sustain the productivity of these land resources. Availability of irrigation leads to land use change as well as intensive cropping system. Improper use of irrigation water has resulted in degradation of natural resources that leads to decline in the productivity of land resources and deterioration of land quality for its future use (Sulieman *et al.*, 2015).

So as to address this water challenge, Geographic Information System (GIS) based Multi-Criteria Land Suitability Analysis (MCLSA) techniques were applied.

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The techniques can handle large volumes of datasets considering all spatial factors to select surface irrigation site. Kumi-Boateng *et al.* (2016) suggested that GIS based Multi-Criteria Evaluation Land Suitability Analysis (MCELSA) techniques are possible way of making optimal decisions in selecting suitable land for dam or surface irrigation. GIS based Multi-criteria evaluation (MCE) techniques are the numerical algorithms that define suitability of solution based on input criteria and weights together with some mathematical or logical means of determining trade-offs when conflicts arise. In this technique, weight can be assigned to the geospatial dataset from various sources to reflect their relative importance (Abeyou *et al.*, 2012) and overlaid using GIS-based multi-criteria analysis techniques in the ArcGIS software environment. Therefore, this study was aimed at identifying suitable areas on GIS-based MCE for surface irrigation along the Erer Watershed of Eastern Hararghe Zone, Ethiopia.

2. Materials and Methods

2.1. Description of the study area

The study area, Erer watershed, is one of the largest watersheds of the Shebelle basin in Eastern Hararghe Zone with a total area of 386,731 ha. It lies between 8° 20'N and 9° 20'N latitude and 41° 40'E and 42° 30'E longitude (Fig. 1). Elevation of the watershed ranges between 886 m and 2,885 m above sea level (Fig. 1). In the watershed, there are traditional small-scale irrigations managed by local farmers along the Erer River. According to the data collected from Ethiopian National Meteorological Services Agency, this region receives 523.4 mm of mean annual precipitation with an average temperature that varies from 10.5°C to 32°C. The River Erer with 138.35 km length emanates from an elevation of about 2,885 m in the Eastern Hararghe Highlands (Fig. 1).

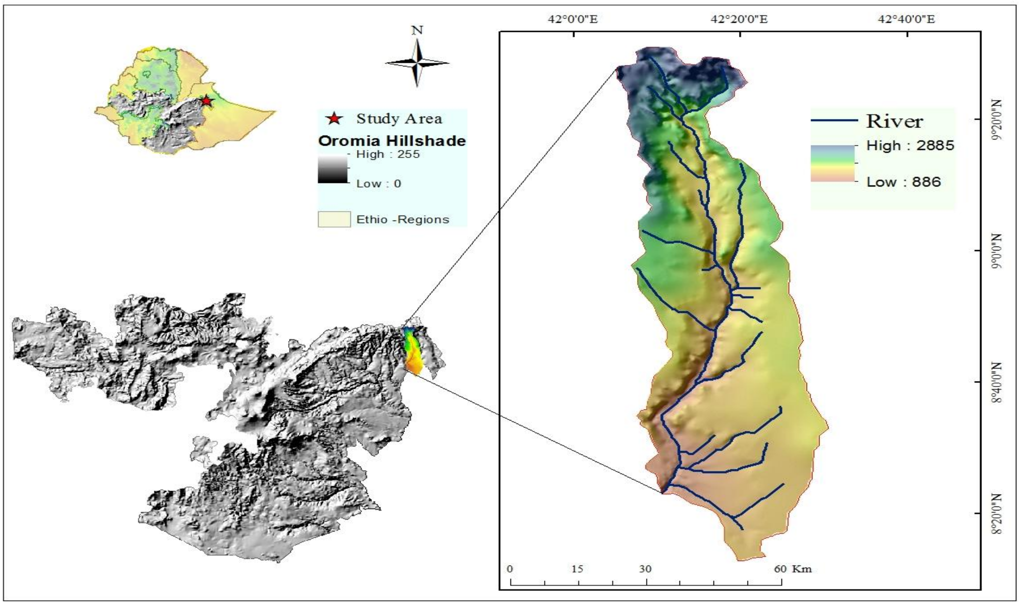

Figure1. Map of the Study Area

2.2. Methods

2.2.1. Data and Materials

Topographic map (1:50,000) and Aerial Photograph (1:250,000) of the study area were collected from the Ethiopian Mapping Agency (EMA). The project area was selected based on topography and access to irrigation water supply. Information was collected on climate, soil and vegetation cover of the study area from available documents. Interpretation and identification of land features was made using the existing 1:250,000 and 1:50,000 scale aerial photograph and topographical maps, respectively. The watershed and river networks were delineated from Digital Elevation Model (DEM) using Arc hydro tools extension in Arc map environment. The data were then integrated with other data in the ArcGIS software version 10.3. The DEM from the Advanced Space-borne Thermal Emission and Reflection Radiometer (SRTM) was used for topographic analysis. Soil data were downloaded from Harmonized World Soil Database (HWSD) website (Nachtergaele *et al.,* 2009). These digital datasets were imported and integrated in the ArcGIS environment. In addition, frequent field observations were carried out to collect the ground truth of Land-use/Land-Cover using hand-held Global Positioning System (GPS). Meteorological data were collected from National Meteorological Agency (NMA). Landsat 8 Operational Land Imager (OLI) image of 2015 and ASTER DEM were downloaded from USGS website.

2.2.2. Preparation of Database

Since the primary issue in MCE is concerned with how to combine the information from several criteria to form a single index of evaluation, series of base maps and images were prepared to facilitate the processing, data integration and functionality of GIS software (Eastman, 2001). All preprocessing activities such as downloading, extracting, geo-referencing, formatting and resampling digital data of the factors were done before analysis. First, the main watershed, sub watersheds, river networks, slope and outlets were delineated from DEM (30m) using Arc hydro tools in GIS platform. Then, LULC map was generated from Landsat8 satellite imagery (Kassaye *et al.*, 2018 and Fig. 2). Finally, twelve soil factors were extracted from Harmonized World Soil Database Version 1.2.

Table 1. Spatial Database and Sources.

Data type	**Source**
Meteorological data	National Metrological Agency (NMA)
Ground Control Points (GCP's)	GCPs were collected from each LULC
Soil Data	Harmonized World Soil Database Version 1.2
Topographic map and Aerial photograph	Ethiopian Mapping Agency (EMA)
Key informant Interview	Experts in the field
Digital Elevation Model (DEM)	ASTER website
Landsat8 (OLI)	USGS portal *http://www.earthexplorer.usgs.gov.*

Table 2. Software Packages and Devices.

Software's and Instruments	**Application**
ArcGIS10.3	Data Visualization and Map Layout
ERDAS IMAGINE 2013	Image preprocessing and Classification
ElShal Smart GIS	Download Rectified Google Earth Image
IDRISI 32	Weighting Influencing percentage
ENVI 5.2	Image Correction
Google Earth	Ground verification
Digital Camera	Collect Ground Truth
GPS(Garmin72H)	Collect Ground control Point (GCP's)

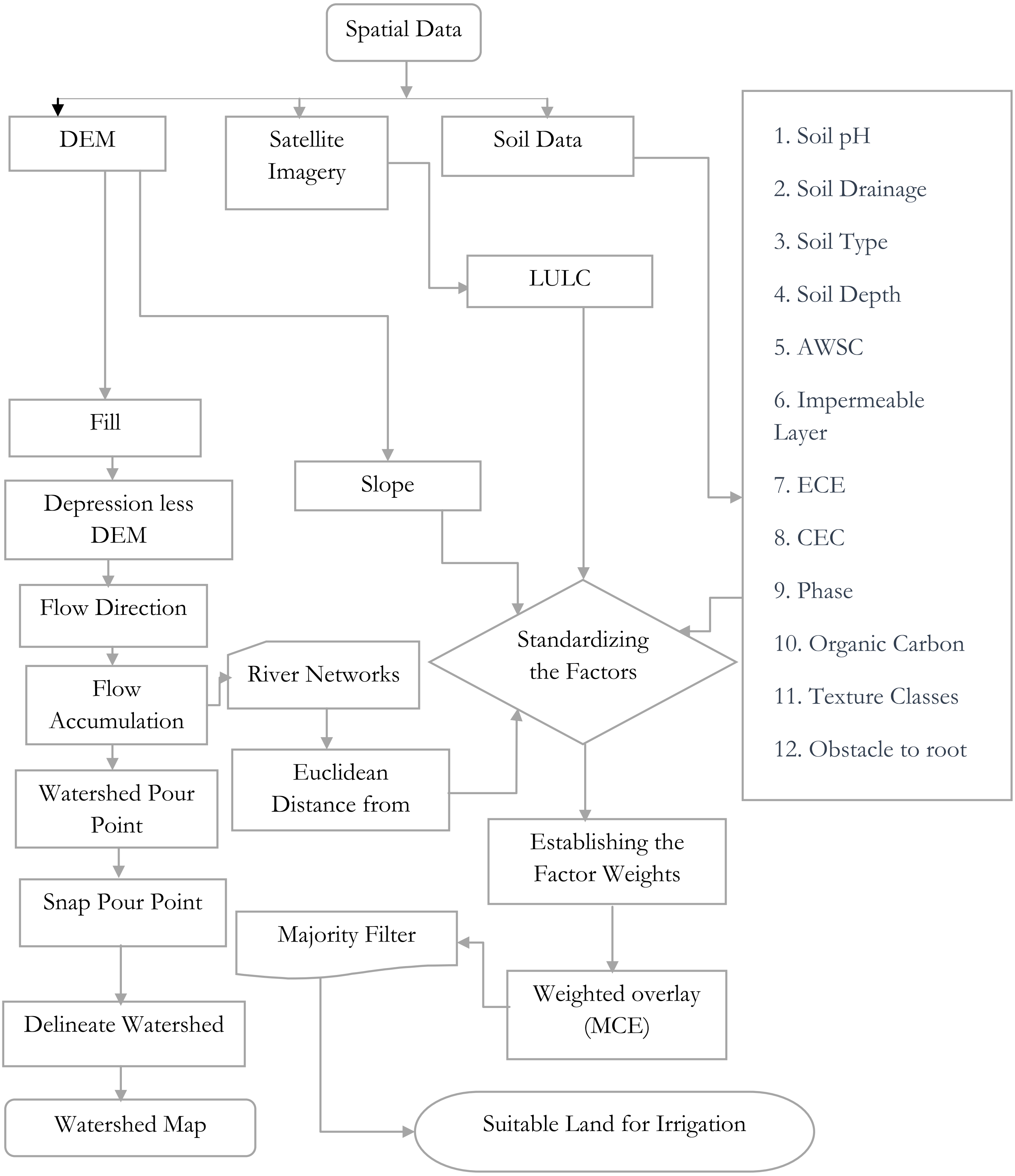

Figure 2.Flow chart of Suitable land analysis for surface irrigation

2.2.3. Factors used to map land suitability for surface irrigation

Factors that affect the suitability of an area for surface irrigation were identified based on literature and expert opinion (Worqlul *et al.*, 2017). Fifteen factors were used to assess the suitability of surface irrigation. The factors (sub models) were soil pH, soil type, soil drainage, soil depth, available water storage capacity (AWSC), impermeable layer (IL), cation exchange capacity (CEC), electrical conductivity (ECE), phase, organic carbon (OC), texture classes (TC), obstacle to root crops (ORC), land use /land cover (LULC), slope (S), and distance from the river outlets (DWS) to find suitable land for surface irrigation.

2.2.3.1. Soil

Soil is a key factor in determining the suitability of an area for agriculture and sustained irrigation (Dagnenet, 2013 and USDIBR, 2003). Its primary influence is on the productive capacity, but it may also influence production and development costs. Both the spatial and attribute soil data were obtained from the Harmonized World Soil Database (HWSD) version 1.2. As USDIBR (2003) stated that several soil characteristics must be evaluated to determine soil suitability for irrigation. The primary factors are soil-moisture relationships, toxicity, fertility, depth to gravel and cobble, continuing layer, and the erosion hazard. Therefore, for this study Chemical (pH, organic carbon, AWSC, CEC, ECE) and physical (soil type, soil drainage, soil depth, obstacle to roots of crops, impermeable layer, phase and texture classes) primary soil factors were extracted from HWSD (Table 3 and 4 and Fig. 3). Table 3 and 4 illustrate the detail agronomical significances of each soil factors extracted from HWSD which has been compiled by Food and Agriculture Organization of the United Nations (FAO), International Institute for Applied Systems Analysis (IIASA), ISRIC-World Soil Information Institute of Soil Science – Chinese Academy of Sciences (ISSCAS) and Joint Research Centre of the European Commission (JRC) (Nachtergaele *et al.*, 2009).

Phases are subdivisions of soil units based on characteristics which are significant for the use or management of land. They are used, for example, where indurated layers or hard rock occur at shallow depth (FAO, 1995). The soil map of Erer Watershed contains four phases which are lithic, gravelly, sodic and no phase. As it is stated in HWSD Version 1.2, lithic phase is used when continuous coherent and hard rock occurs within 50 cm of the soil surface; the sodic phase marks soils which have more than 6 percent saturation with exchangeable sodium in some horizons within 100 cm of the soil surface. The gravelly phase is used to indicate over 35% gravels with diameter < 7.5 cm (Nachtergaele *et al.*, 2009).

Table 3. Agronomic Significances of Chemical Soil Factors for land suitability assessment of surface irrigation

Criteria	Parameter	Agronomic Significances of the soil	Source
AWSC (mm/m)	<15	very low Available water storage capacity	Nachtergaele *et al.*, 2009
	15 - 75	low Available water storage capacity	
	75 - 100	moderately good for most crops	
	> 100	Optimum for most crops	USDIBR, 2003
CEC (cmol kg-1)	< 9	Very low nutrient storage capacity for most crops	Nachtergaele *et al.*, 2009
	9 - 12	low nutrient storage capacity for most crops	
	12 - 13	marginally good nutrient storage capacity for most crops	USDIBR, 2003
	> 13	considered satisfactory nutrient storage capacity for most crops	
ECE (dS m-1)	< 0.1	Very low salt content ideal for crops	Nachtergaele *et al.*, 2009
	0.1 - 1.1	Moderate salt content	
	> 1.1	High salt content most crops do not resist	
OC (%)	<0.7	Invariable need organic or inorganic fertilizer	Nachtergaele *et al.*, 2009
	0.7 - 0.74	poor in organic matter	
	0.74 - 1.15	Marginally good for crops	USDIBR, 2003
	1.15 - 2.18	Moderately good for crops	
	> 2.18	Optimum for crops	
pH	> 4.4	Extremely acid soils include Acid Sulfate Soils	
	4.4 - 5.4	Very acid soils. Some crops are tolerant this (Tea, Pineapple).	USDIBR, 2003
	5.4 - 6.5	Acid to neutral soils: these are the best pH conditions for nutrient availability and suitable for most crops.	
	6.5 - 6.6	Carbonate rich soils.	Nachtergaele *et al.*, 2009
	> 6.6	Indicates alkaline soils often highly sodic (Na reaching toxic levels),	

Table 4. Significances of physical Soil Factors for land suitability assessment of surface irrigation.

Criteria	Parameters	Agronomic Significances for Surface Irrigation	Source
Drainage	Well Moderately Well Imperfectly Poor excessive	Optimum moderate marginal Not ideal for upland crops has little significance	Nachtergaele *et al.*, 2009
Phase	Sodic Gravelly Lithic No Phase	optimum moderate very low no data	Nachtergaele *et al.*, 2009 USDIBR, 2003
Impermeable layer (cm)	>150 <40	Optimum not optimum	Nachtergaele *et al.*, 2009
Obstacle to roots (cm)	> 80 40 - 60 20 - 40	Optimum modrate low	Nachtergaele *et al.*, 2009
Soil Depth(cm)	< 10 .10 - 50 50 - 100 > 100	very low low Marginal Optimum	Mandal *et al.*, 2017
Soil Type	Chromic Luvisols Humic Nitosols Eutric Vertisols Haplic Calcisols Rendzic Leptosols Lithic Leptosols	Optimum Moderate marginal low very low very low	FAO and UNESCO,1988
Texture Classes	Sandy Loam Loamy Sand Loam Silt Loam	Marginal low Optimum Moderate	USDIBR, 2003 Mandal *et al.*, 2017

2.2.3.2. Slope

Slope is the principal topographic characteristic which determines suitability of land for irrigation. It affects the suitability of an area in terms of land preparation for irrigation and irrigation operation (USDIBR, 2003). It influences method of irrigation, land development, design of on farm irrigation systems, erosion hazard, drainage requirements, water use practices, crop, and other management and production costs. Thus, the study of slope is a principal factor for land suitability study for surface irrigation. The slope of the watershed was extracted from 30 m resolution DEM and was classified in to four classes (0 – 2%, 2 – 5%, 5 – 8% and > 8%) based on (FAO, 1979) and United State Department of the Interior Bureau of Reclamation (USDIBR, 2003) technical guidelines for suitability land classification method for surface irrigation.

2.2.3.3. Land use land cover

Land use data help to identify the productivity of an area for irrigation. To generate and analyze the LULC suitability map for surface irrigation, the Landsat 8 Operational Land Imager (OLI) image was downloaded from USGS website. The land sat imagery was classified in to six major land use classes (bare land, bush land, dispersed forest, farm, range land and settlement). The land use group was classified into four classes ranging from highly suitable (class S1) to not suitable (Class S4). Table 6 presents the FAO framework of land suitability classification. Farm land use types were classified as highly suitable (S1) and rangeland, which requires land clearing and leveling, as moderately suitable (S2). Bush land which requires higher initial investment for land preparation, were reclassified as marginally suitable (S3). Dispersed forest, settlement and bare land use types were reclassified as not suitable (S4).

2.2.3.4. Distance from water supply (source)

To identify irrigable land close to the water supply (rivers), four (from 0 – 5, 5 - 10, 10 – 20 and > 20 km^2) buffer zone distance were generated from the watershed outlets and was reclassified. (Mandal *et al.*, 2017). Then reclassified distance map was used for weighted overlay analysis along with other factor maps (Table 5). Distance from water source is the highest weighted factor which accounts 18% of the influences among the other factors (Table 9). This is to reduce cost for redirecting the water to the command area.

Table 5. Agronomic Significances of other physical factors for land suitability assessment of surface irrigation.

Criteria	Parameter	Agronomic Significance	Source
Euclidean Distance (km)	0 - 5	optimum	Mandal *et al*, 2017
	5 - 10	moderate	
	10 - 20	marginal	
	> 20	low	
LULC	Rangelands	Moderate	
	Farmland	Optimum	
	Dispersed Forest	Low	
	Settlement	Not optimal	
	Bush	Marginal	
	Bare land	Not optimal	
Slope (%)	0 - 2	Optimum	Mandal *et al*, 2017
	2 - 5	Moderate	USDIBR, 2003
	5 - 8	Marginal	Buhari, 2014
	> 8	Low	

2.2.4. Structure of Land suitability classifications

Land suitability is the fitness of a given type of land for a defined use by Food and Agricultural Organization (FAO, 1976). The FAO (1976 and 2007) proposed an approach for land suitability evaluation in terms of suitability ratings from highly suitable to not suitable based on the suitability of land characteristics to different crops. According to FAO (1976 and 1983), land suitability maps are generally classified into two orders, i.e., Suitable(S) and not suitable (N). These orders are further classified in to three and two classes respectively based on their benefits and limitations: highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and temporarily not suitable S4 (N1) and permanently not suitable S5 (N2) respectively (Table 6).

Table 6. Framework of land suitability classification.

Class	Land Description
S1 Highly Suitable	Land without significant limitations. This land is the best possible and does not reduce productivity or require increased inputs.
S2 Moderately Suitable	Land that is clearly suitable but has limitations that either reduce productivity or require an increase of inputs to sustain productivity compared with those needed on S1 land.
S3 Marginally Suitable	Land with limitations so severe that benefits are reduced, and/or the inputs required sustaining production need to be increased so that this cost is only marginally justified.
N1 Currently Not Suitable	Land having limitations which may be surmountable in time, but which cannot be corrected with existing knowledge at currently acceptable cost; the limitations are so severe as to preclude successful sustained use of the land in the given manner.
N2 Permanently Not Suitable:	Land having limitations which appear as severe as to preclude any possibilities of successful sustained use of the land in the given manner.

Source: FAO, 1976 and 1981

2.2.5. Derivation of Criterion Maps

Deriving datasets is the step after having defined the problem and breaking it into sub models when building a suitability model based on multi criteria evaluation (ESRI, 1996). Selection of evaluation criteria in this study was based on project objective, spatial scale, and, data availability. Thus, the study aimed at considering fifteen factors (sub models) , namely, soil pH, soil type, soil drainage, soil depth, AWSC, impermeable layer, ECE, CEC, phase, organic carbon, texture classes, obstacle to root, land use /land cover, slope, and distance from the river outlets to find suitable land for surface irrigation. Criterion maps or datasets were derived to each factor in GIS environment (Fig. 3). Soil datasets with the attribute were derived from HWSD (Table 3 and 4). Land use/ land cover dataset was derived from Landsat 8 satellite imagery and slope was derived from DEM (Fig. 3 and Table 5). Finally, to find ideal site away from the river, the Euclidean (straight-line) distance was derived from the river's outlet points (Fig. 3 and Table 5). These attributes were used to create the criterion maps database in Arc GIS (Fig. 3

and Table 3, 4 and 5). The criterion maps were standardized to a common numeric range for further processing that was establishing the factor weights (ESRI, 1996).

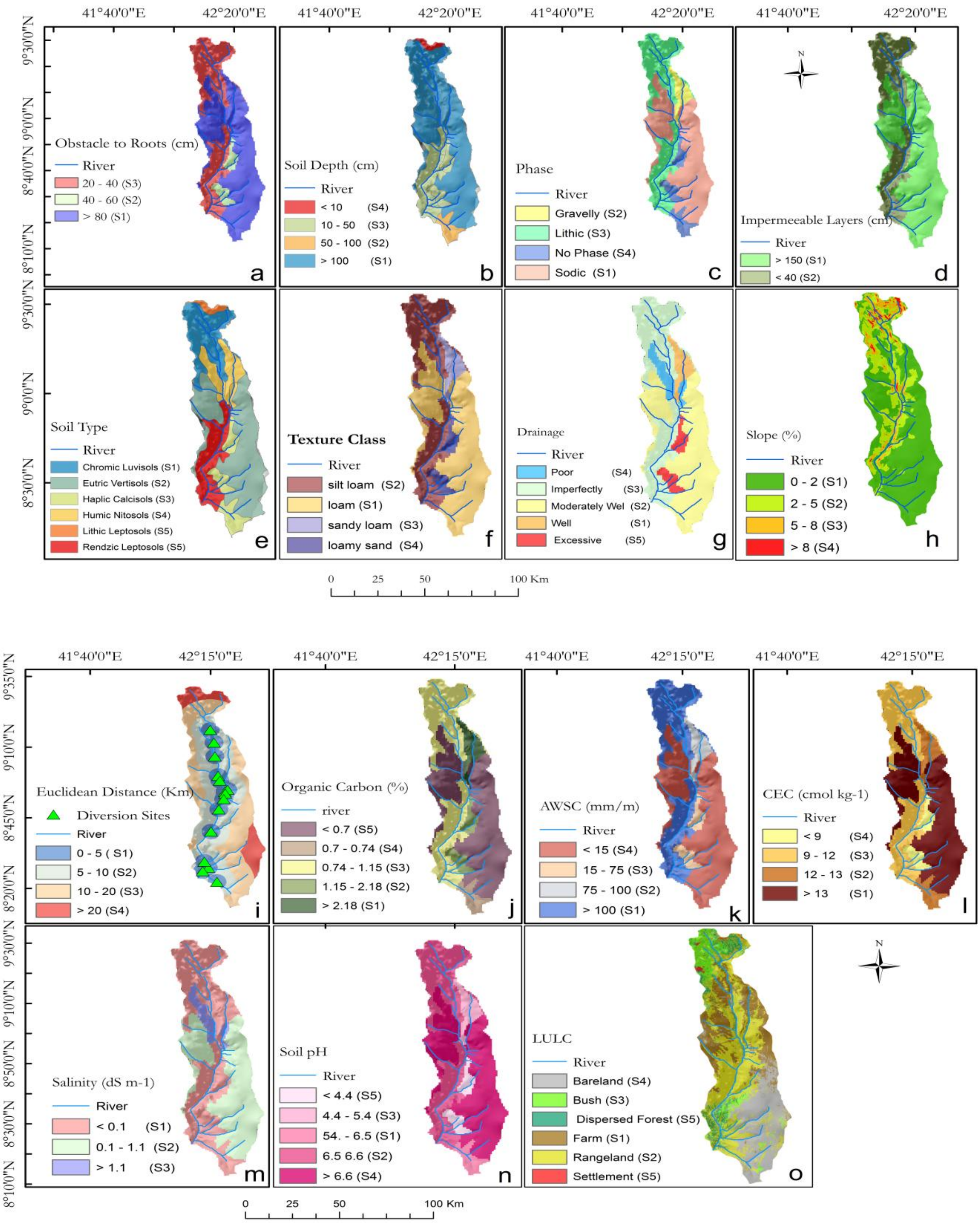

Figure 3. Factors maps and level of suitability to assess optimum location for surface irrigation: (a) Obstacle to roots of crops, (b) Soil Depth, (c) Phase of the Soil, (d) Impermeable Layer, (e) Soil Type, (f) Soil Texture Class, (g) Drainage (h) Slope (i) Distance from water sources (j) Soil Organic Carbon (k) Available Water Storage Capacity, (l) Cation Exchange Capacity, (m) Soil Salinity, (n) Soil pH and (o) Land Use Land Cover.

2.2.6. Standardizing the Factors

Each of the factors was standardized using the module reclassify so that the results represent a common numeric range giving higher values to more suitable attributes (Fig. 3). Reclassification is the method to assign values of preference, sensitivity, priority, or some similar criteria to a raster (ESRI, 2011). As it was quantified in tables 3, 4 and 5, the factors were reclassified as per the spatial existence of the factors in the study area. As a result, of the fifteen factors, impermeable layer has the smallest classes whereas soil type and land use have the largest classes (Fig. 3). The reclassification process was done based on the five classes of agricultural land suitability for irrigation according to the FAO framework (FAO, 1976, 1985; Mandal *et al.*, 2017and Table 6).

2.2.7. Establishing the Factor Weights

This stage was done to establish a set of weights for each of the factors. In this stage, the importance or preference of each criterion relative to the rest of the criteria on suitable land selection was expressed by assigning weights (ESRI, 2012). This was done based on related review literatures, field observation and on expert judgment to fill out a pairwise comparison matrix from which a set of weights referred to as Eigenvectors together with consistency ratios were generated for each of the criteria being considered (Chen *et al.*, 2010; Gizachew and Yihenew, 2015). The available values for the comparison are the member of the set: {9, 7, 5, 3, 1, 1/3, 1/5, 1/7, 1/9}, with 9 representing absolute importance and 1/9 the absolute triviality (Saaty, 1980; Saaty and Vargas 1991 and Table 8). Then the factor weights were evaluated to undertake the multi-criteria evaluation of suitability for surface irrigation development.

Table 7. Factors for surface irrigation land suitability assessment.

Factors	Parameters	Suitability	Eigenvector of weights	Weight (%)
Drainage	Well	S1		
	Moderately Well	S2		
	Imperfectly	S3	0.0408	4.08
	Poor	S4(N1)		
	excessive	S5(N5)		
Phase	Sodic	S1		
	Gravelly	S2	0.0345	3.45
	Lithic	S3		
	No Phase	S4(N1)		
Impermeable layer (cm)	>150	S1	0.1108	11.08
	<40	S2		
Obstacle to roots of crops(cm)	> 80	S1		
	40 - 60	S2	0.1229	12.29
	20 - 40	S3		
Soil Depth(cm)	< 10	S4(N1)		
	10 - 50.	S3	0.0404	4.04
	50 - 100	S2		
	> 100	S1		
Soil Type	Chromic Luvisols	S1		
	Humic Nitosols	S2		
	Eutric Vertisols	S3	0.0322	3.22
	Haplic Calcisols	S4(N1)		
	Rendzic Leptosols	S5(N2)		
	Lithic Leptosols	S5(N2)		
Texture Classes	Sandy Loam	S3		
	Loamy Sand	S4(N1)	0.059	5.9
	Loam	S1		
	Silt Loam	S2		
Available water	< 15	S4(N1)		

storage capacity (mm/m)	15 - 75	S3	0.0634	6.34
	75 - 100	S2		
	> 100	S1		
Cation exchange capacity (cmol kg-1)	< 9	S4(N1)		
	9 - 12.	S3	0.0744	7.44
	12 - 13.	S2		
	> 13	S1		
Electrical conductivity of Soil (dS m-1)	< 0.1	S1		
	0.1 - 1.1	S2	0.0351	3.51
	> 1.1	S3		
	< 0.7	S5(N2)		
	0.7 - 0.74	S4(N1)		
Organic Carbon (%)	0.74 - 1.15	S3	0.0388	3.88
	1.15 - 2.18	S2		
	> 2.18	S1		
	< 4.4	S5(N2)		
	4.4 - 5.4	S3		
pH	5.4 - 6.5	S1	0.0292	2.92
	6.5 - 6.6	S2		
	> 6.5	S4(N1)		
Euclidean Distance(km)	0 - 5	S1		
	5 -10.	S2	0.18	18
	10 - 20.	S3		
	> 20	S4(N1)		
LULC	Rangelands	S2		
	Farmland	S1		
	Dispersed Forest	S4(N1)	0.0369	3.69
	Settlement	S5(N2)		
	Bush	S3		
	Bareland	S4(N1)		
Slope (%)	0 - 2	S1		
	2 - 5.	S2	0.1017	10.17
	5 - 8.	S3		
	> 8	S4(N1)		

After the pairwise comparison matrices were filled, the weight module of IDRISI software was used to identify inconsistencies and develop the best fit weights (Table 9). The technique described here and implemented in the IDRISI software was that of pairwise comparisons developed by Saaty (1977) in the context of a decision-making process known as the Analytical Hierarchy Process (AHP).

Table 8. Scale for pair-wise comparisons (Saaty and Vargas, 1991).

Intensity of importance	Description
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values
Reciprocals	Values for inverse comparison

2.2.8. Undertaking the Multi-Criteria Evaluation

Once the weights were established, the module Weighted Overlay tool (for Multi-Criteria Evaluation) was used to combine the factors for undertaking multi-criteria evaluation (Fig. 4). With a weighted linear combination, factors are combined by applying a weight to each followed by a summation of the results to yield a suitability map i.e.:

$$S = \sum w_i x_i$$

Where S = suitability; wi = weight of factor I; xi = criterion score of factors i

The procedure is optimized for speed and has the effect of multiplying each factor by its weight, adding the results, and then successively multiplying the result by each of the factors. The Eigenvectors weights and weights sum (the total influence for all factors) to 1 and 100 percent, respectively (Table 9). GIS and MCE techniques are globally recognized for its outstanding support in map overlay process for any form of land suitability analysis (Carver, 1991 and Malczewski, 1999).

The primary issue in MCE is concerned with how to combine the information from several criteria to form a single index of evaluation (Eastman, 2001). Prioritization and selection of criteria's influence was executed by reviewing important literatures related to this study and supplemented by opinion of experts in the field and other stake holders based on their preliminary knowledge and fair judgment (Eastman, 2006). The basic advantages of using MCE techniques are related to possibilities to evaluate all factors at different scales. Moreover, it enables the researchers to merge information gathered from different criteria based on their relative weights guided by experts' knowledge to produce single out put map (Ebistu *et al.*, 2013; Malczewski, 2004 and 2006) and (Fig. 4). Finally, Majority filter tool was used to refine optimal areas for surface irrigation (ESRI, 2008).

4. Results and Discussion

4.1. Effect of Factors for Surface Irrigation Suitability Mapping

The result of the pair-wise comparison matrix showed that fifteen of the major factors were compared one-to-one and scored using a Saaty scale (Saaty, 1977). The eigenvector was calculated as the product of the row matrix and the weights of each factor were calculated by normalizing the respective eigenvector weight (EW) by the cumulative vector. Table 9 shows the weights of importance or preference of each criterion relative to rest of the criteria on suitable land selection. As a result, physical factors such as distance from water source (DWS), obstacle to roots of crops (ORC), impermeable layer (IL), lithic phase and slope(S) were the most important factors for determining the suitability of the watershed for irrigation followed by cat-ion exchange capacity (CEC), available water storage capacity (AWSC) and texture classes(TC), soil drainage(DR) and soil depth(SD); with 7.44%, 6.34% and 5%, 4.1% and 4.04%, of weight of influence respectively. Land use land cover (LULC), electrical conductivity (EC), organic carbon (OC), pH, and soil type were listed as less important, with 3.69, 3.51%, 3.88% 2.92% and 3.22% weight of influence respectively (Table 9). Table 9 presents the results of the pair-wise comparison matrix and influences of weights of factors.

Table 9. Pairwise comparison matrix for assessing the comparative importance of fifteen factors

	AWSC	CEC	DR	EC	DWS	Phase	IL	LULC	OC	ORC	PH	S	SD	ST	TC	EW	W (%)
AWSC	1															0.0634	6.34
CEC	1	1														0.0744	7.44
DR	1/2	1/3	1													0.0408	4.08
EC	1/2	1/3	1	1												0.0351	3.51
DWS	2	3	2	3	1											0.18	18
Phase	1/2	1	1/2	1	1/5	1										0.0345	3.45
IL	2	3	2	2	1/2	2	1									0.1108	11.08
LULC	1/2	1/3	1	1	1/3	1	1/5	1								0.0369	3.69
OC	1/2	1/5	2	1	1/4	2	1/4	2	1							0.0388	3.88
ORC	2	5	2	3	1/5	5	2	2	3	1						0.1229	12.29
PH	1/4	1/4	1/2	1/2	1/7	1/2	1/4	1/2	1	1/5	1					0.0292	2.92
S	2	2	5	2	1/2	2	1	2	2	1	2	1				0.1017	10.17
SD	1	1/2	1	2	1/3	1	1/2	1	1	1/2	2	1/3	1			0.0404	4.04
ST	1/2	1/3	1	1	1/5	1	1/2	1/2	1	1/3	1/4	1/4	2	1		0.0322	3.22
TC	1	1	1	3	1/5	1/3	1/5	2	2	1/3	2	1/3	3	2	1	0.059	5.9
																1.0001	100

Consistency ratio = 0.07

Consistency is acceptable.

The credibility of the pairwise matrix consistency was evaluated using consistency ratio. The result was found to be trustworthy with a consistency ratio of 0.07 (Eastman, 2006 and Worqlul *et al.*, 2017).

4.2. Land suitability analysis

Land suitability analysis for surface irrigation at a catchment scale is an interdisciplinary approach by including the information from various sources such as climate, topography, soils, LULC and distance form water source (Bojorquez *et al.*, 2001). Potentially surface irrigable land was identified based on the specified suitable criteria by creating irrigation suitability model analysis which involved weighting of values of all the fifteen sub models (factors dataset). The weighted criterions (Table 9) were aggregated to produce a final suitability map according to defined regulation in ArcGIS (Fig. 4). The resultant map showed the extent of distribution of the land suitability classes (Fig. 3 and Table 10). To this effect, out of the total area of the watershed which is 386,731 ha, a small portion of about 45,080 ha (11.7%) of the watershed was assessed highly suitable for surface irrigation due to factors such as gentle slope (0–2%), absence of obstacle to root up to 80 cm depth, absence of impermeable layer within 150 cm soil depth, soil depth greater than 100 cm, closest distance to water sources(0–10 km^2) and non-lithic phase (Fig. 3). The second portion of 50,223ha (12.98%),) of the total area of the watershed was calculated as moderately suitable land for surface irrigation due to moderate slope (2–5%), moderate cation exchange capacity (12–13 cmol km^{-1}) and gravelly soil texture (Fig. 3). The largest part of the watershed 151,120ha (39.07%) of the total area was evaluated as marginally suitable because of factors such as acidic soil pH, low organic carbon content of the soil, low available water storage capacity of the soil and long distance from water sources (10–20 km). The marginally suitable land is in the western and south western part of the watershed. Lastly, the second largest part 140,308 ha (36.3%) of the total area of the watershed was found to be unsuitable land for surface irrigation due to physical constraints such as steep slope (> 8%), stoniness, presence of impermeable layer with in 40cm depth, longest distance from water source (> 20km) in the Northern part, shallow soil depth, very low cat-ion exchange capacity(< 9km-1) and presence of obstacle to roots of crops from 20 – 40 cm depth (Fig. 3). As seen from the map in figure 4, the largest part of unsuitable land is in the northern and south west central part of the watershed. Although the south west central part of the watershed is located close to the water source and has ideal available water storage capacity, it is unsuitable for surface irrigation due to its steep slope (> 8%), shallow soil depth (10 – 50 cm), imperfectly soil drainage and lithic phase (Fig. 3 and 4). While the northern part of the watershed has ideal soil depth, soil type, soil texture, soil salinity and available water storage capacity, it was found to be unsuitable land for surface irrigation because of the physical limitations such as very high steep slope (> 8%), high distance from water sources (> 20 km), lithic phase, presence of impermeable layer (20 – 40 cm) and obstacle to root with in 40cm depth (Fig. 3).

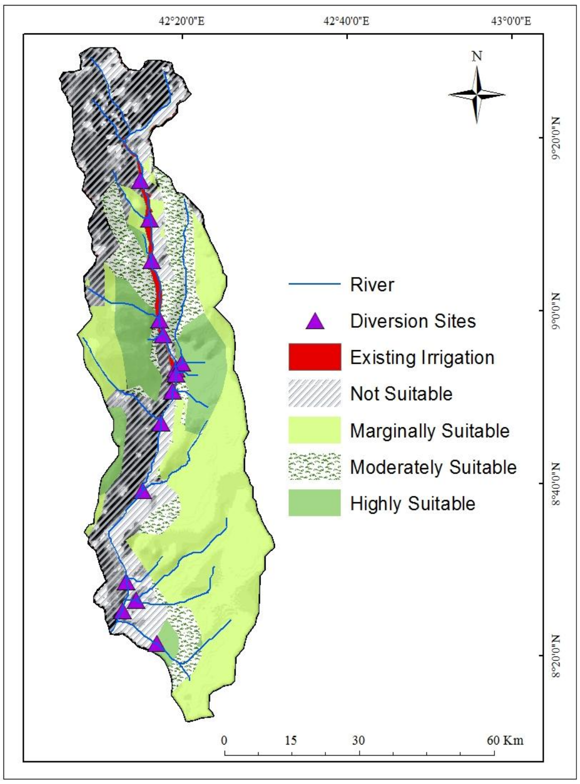

Figure 4. Surface Irrigation Suitability Map

Almost the entire study area, CaSo4 (gypsum and CaCo3 (lime) were not considered as limiting factors. This is because the content of both CaSo4 and CaCo3 uniformly distributed with values from none to very low (0 – 0.1%) and from none to moderate (0 – 9%) respectively. This is consistent the findings of Nachtergaele *et al.* (2009) who reported that up to 2 percent gypsum in the soil favors plant growth, between 2 and 25 percent has little or no adverse effect if in powdery form, but more than 25 percent can cause substantial reduction in yields. The authors added that low levels of calcium carbonate (CaCo3) enhances soil structure and are generally beneficial for crop production but at higher concentrations they may induce iron deficiency and when cemented limit the water storage capacity of soils. Thus, the content of both $CaSo_4$ and $CaCo_3$ is ideal for most crops in the study area.

In agreement with Albaji et al. (2009) and Abraham et al. (2013) the overall result showed that physical factors highly determined the suitability of the study area for surface irrigation. Albaji et al. (2009) reported that the most limiting factors for surface irrigation were physical parameters such as slope, stoniness and soil depth. Corroborating this suggestion, Abraham et al. (2013) stated that high slope; gravelly soil texture and shallow soil depth were limiting factors of land suitability evaluation for irrigation in their study area.

Furthermore, the total area of the existing irrigation is about 4720.14 ha from which, 1506 ha, 1262.14 ha and 1952 ha were found to be moderately suitable, marginally suitable, and unsuitable land classes, respectively. None the existing irrigation land was found to be suitable land classes.

Table 10. The distribution of land suitability classes in the study area.

Suitability	Area(ha)	Percent
Not Suitable	140,308	36.3
Marginally Suitable	151,120	39.07
Moderately Suitable	50,223	12.98
Highly Suitable	45,080	11.7
Total	386,731	100.5

5. Conclusion

The study has demonstrated that GIS techniques are an essential tool for the surface irrigation site suitability evaluation. Fifteen factors were used to assess the land suitability site for surface irrigation. The result of pair-wise comparison matrix showed that fifteen of the major factors were compared one-to-one and scored using a scale from Saaty (1977). The most important limiting factors were distance from water source, obstacle to roots of crops, presence of impermeable layer, slope, and cation exchange capacity with weight of influence of 18%, 12.29%, 11.08%, 10.17% and 7.44% respectively. The study has demarcated areas and produced potential land suitability map of the watershed that will allow growing the right crops at the right site for optimum yield and optimum return to investment for each crop. The result showed that out of the total area of the watershed (386,731ha), 36.3%, 39.07%, 12.98% and 11% were found to be not suitable, marginally suitable, moderately suitable and highly suitable respectively. Furthermore, the result of surface irrigation assessment for land suitability showed that the total area of the existing irrigation is about 4720.14 ha from which, 1506 ha, 1262.14 ha and 1952 ha were found to be moderately suitable, marginally suitable and unsuitable land classes respectively. The existing irrigation land is not suitable for irrigation in general and for surface irrigation in particular based on the factors which were discussed in this study. Suitability for growing crop is limited not only by the selected edaphic constraints but also by socioeconomic factors which should be considered for further studies.

Further research should be conducted to calculate the crop water requirement of the irrigable land of the study area.

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