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Land Suitability Evaluation for Surface Irrigation Using arcGIS and Analytical Hierarchy Process Techniques in Bedessa River Basin, Gedio Zone, Ethiopia

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ABSTRACT

Although the primary goal of this paper is exploration, weighted index overlay analysis is used to assess the quality of land for surface irrigation in Ethiopia's Bedessa watershed using a geographic information system (GIS) and the Analytical Hierarchy Process (AHP). The study took into account five critical factors: slope, soil, precipitation, land use/land cover (LULC), proximity to a watercourse, and proximity to a road. The weight of each parameter according to percent of influence on land suitability potential was determined by Analytical Hierarchy Process according to the relative influence of each. The generated land suitability potential for surface irrigation map has four ranks, S1, S2, S3 and N, in which its classes are most suitable, more suitable, less suitable, and individually not suitable, respectively, based on its land suitability potential availability rank and class. The area coverage is 1.81%, 5.64% and 86.83%, 72% of the study area, respectively. The irrigation requirements of the chosen crops were calculated using Crop Wat 8.0 models, and the results indicate that irrigation water requirements were higher during the driest months of the year. Finally, the potential irrigable area was determined by calculating the gross irrigation demand of the known irrigable area in relation to the monthly accessible watercourse. As a result, the map generated by this platform can be used to locate suitable irrigation locations within the space.

Keywords: ArcGIS, Irrigation Potential, Land Suitability, Slope Suitability, Water Availability.

INTRODUCTION

Irrigation is a key factor for sustainable improvement and poverty reduction. Irrigation water can be obtained from a river or pumped from a well (FAO, 2000). The annual groundwater potential is 40 Gm-3 a-1 and the total annual runoff is 122 Gm3 a-1 (Awulachew et al., 2007). There are twelve major river basins in Ethiopia, 9 of which are wet and 3 are dry. The Blue Nile basin in the Ethiopian Highlands provides over 80% of the water used in Sudan and Ethiopia across the Nile. Despite this abundance of water, Ethiopia sustains food resources for only about 10% of the population (Makombe et al., 2007) as the surface water supply is spatially and temporally variable and little is available at the end of the dry monsoon phase (Worqlul et al., 2015).

Today, irrigated farmlands provide around 40% of the world's food. However, irrigated agriculture's ability to provide enough food to feed the world's rapidly expanding population is failing (Bagherzadeh & Paymard, 2015). Only 4% of the 6 million hectares of cultivated land in sub-Saharan Africa, as noted in (Teshome et al., 2013), is irrigated. In Ethiopia, the irrigation subsector only uses roughly 3% of the total water supply (Teshome et al. 2017). Land suitability resources are scarce, especially in the lower Bedessa Basin of the Rift Valley Basin (an area of around 16,076.64 km2), where accessible areas are mostly employed for domestic usage and irrigation and have not undergone enough research.

The surface irrigation planning process must integrate information about soil suitability, water resource availability and water needs for irrigable land at a given time and place (FAO, 2007). Assessing the suitability of land for surface

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irrigation requires a thorough assessment of the soil characteristics and topography (slope) of the land within the field (Fasina et al., 2008). Use of GIS and Remote Sensing (RS) technology applications have now become commonplace for utilities, land surface intelligence and planning. GIS can be a powerful tool to identify suitable irrigable land and to map suitable land for irrigation. RS and GIS tools have been widely used for water resource management (Abeyou et al., 2017). Recently, several studies have been performed using a weighted overlay analysis to evaluate land suitability for surface irrigation. (Abdellatif et al., 2021; Tadele et al., 2021; Garuma et al., 2021; Kassaye et al., 2019 & Lalitha et al., 2016). Among many determinants of land occurrence and movement are suitability for surface irrigation, soil depth, soil type, slope, drainage pattern, precipitation, road, LULC, water quality, water depth and climate (Yonas et al., 2022; Paul et al., 2020; Kassaye et al., 2019 & Biplab et al., 2017). Therefore, the factors examined are different depending on the research, their suitability as determinants for growing plants may be limited and consequently the results vary.

According to a Ministry of Water Resources (MoWR) irrigation development program document prepared for the years 2002-2016, the gross and net irrigation potentials of Ethiopia have been estimated to be 3.73 and 2.23 million hectares, respectively. The total area irrigated until 1991 was 176,015 ha, and this number increased to 197,250 ha in 1998. According to recent data compiled by MoWR from different master plan studies and regions, the area under irrigation in the country increased to about 289,530 ha in 2007 (Gebremedihin et al., 2012). Land suitability resources are primarily used for irrigation and domestic utilities in the Bedessa sub basin of the Rift Valley river basin because the amount of surface water in the area is limited and its availability has not been properly investigated.

The practical development of soil suitability assessment will significantly improve community livelihoods. In fact, mapping surface irrigation potential has a significant impact on improving the long-term management of surface water resources and increasing crop production in both the study area and the country overall. As a result, a thorough investigation was conducted to determine the soil's suitability for surface irrigation for better use. As a result, by defining land suitability zones using remote sensing techniques and GIS tools, this paper help to achieve proper management and sustainable use of surface irrigation for crop production in the sub-basin. The study took into account five determining factors: slope, soil, precipitation, LULC, proximity to a watercourse, and proximity to a road.

MATERIALS AND METHODS

Description of the study area:

This study was conducted in the Bedessa River Basin in Gedio Zone, Ethiopia (Fig. 1). The Bedessa River Basin is geographically located between 6°-11'-6°- 24' North latitude and 38°-16'-38°-24' East longitude. It is 361 km south of Addis Ababa and 92 km from the regional state capital of Hawassa and 2 km from the city of Dilla. Its altitude is between 1449 m and 3029 m above sea level. The climate is highly variable in the highland river basin and in the escarpments that define the rift floor. Rainfall exceeds 1,600 mm/year, while the lowest elevation receives much less rainfall, often below 800 mm/year. According to the Minister of Agriculture (MOA, 2000) classification, the agro ecology of Ethiopia is classified as: Wurch, Dega, Weyna-dega, Kolla and Bereha. The two main crops grown utilizing small-scale surface irrigation in the watershed are maize and tomatoes. Both rain-fed agriculture and conventional irrigated agriculture have been performed there.

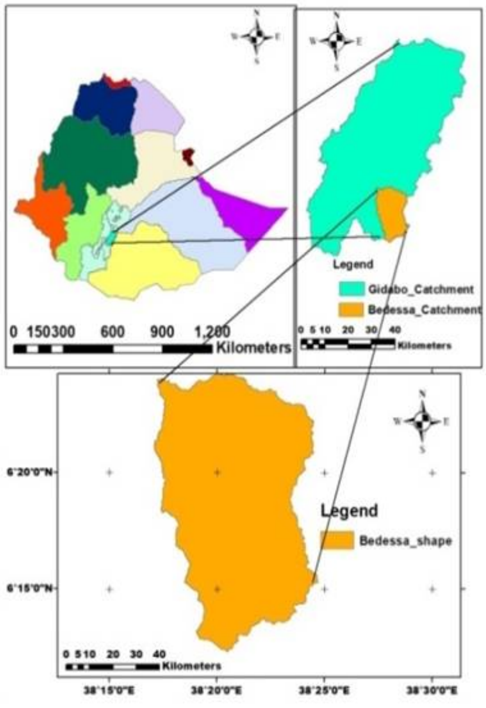

Fig. 1: The geographic location of Bedessa sub-basin

Data Collection:

To achieve study objectives, daily precipitation, temperature, wind speed, hours of sunshine and relative humidity were obtained from the Ethiopian Metrological Service Agency (EMSA). The climate information was used in CROPWAT 8.0 to calculate irrigation water needs for corn, tomato and cabbage soils, and land use data was collected from the Ethiopian Ministry of Water, Irrigation and Electricity (MoWIE). A 30-m resolution Global Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) (http://earthexplorer.usgs.gov/) was used to determine the percentage slope of the watershed on a pixel-by-pixel basis. Stream flow records collected from the Department of Water, Irrigation and Energy on the Bedessa River include records over extended periods from 1993 to 2004.

Methods:

Identification of suitable sites for surface irrigation was carried out by considering the slope, soil type, soil texture, soil drainage, soil depth, land cover/use distance between water supply and proximity to a road. First, the individual suitability of each factor was analyzed and then weighted to get suitable irrigable sites sing the Multi-Criterion Decision Evaluation (MCDE) method in Geographical Information System. Secondly, surface water availability was determined using SWAT model. Thirdly, the gross irrigation requirement of each selected crop (corn, tomato and cabbage) on irrigable land of recognized capacity was determined. Finally, fulfilling an objective of the research, a suitable land map for irrigation was prepared based on GIS analysis.

SWAT Model:

SWAT was developed to measure the impacts of land management practices on water, sediments, and agricultural chemical yields over time in catchments with a variety of soils, land uses, and management conditions (Arnold et al., 2012). Hydrology, climate, nutrient cycling, soil temperature, sediment movement, crop development, agricultural management, and pesticide dynamics are the key components of SWAT. SWAT simulates the water cycle on land using the water balance equation, represented as Equation (1).

$$SW_t = SW_o + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{qw} \quad \ldots\ldots(1)$$

where SWt is the final soil water content (mm), SWo is the initial soil water content on day i (mm), t is time (days), Rday is the amount of precipitation on day i (mm), Qsurf is the amount of surface runoff on day i (mm), Ea is the amount of evapotranspiration on day i (mm),Wseep is the amount of water entering the vadose zone from the soil profile on day i (mm) and Qqw is the amount of return flow on day i (mm).

Sensitivity Analysis of SWT Parameters:

For this study, sensitivity analysis was implemented by the automated software SWAT Calibration and Uncertainty Program (SWAT-CUP) using the commonly applied Sequential Uncertainty Fitting algorithm (SUFI2) (Abbaspour et al., 2007). Sixteen parameters were used for analysis for this study (Neitsh et al., 2005) as displayed in Table 1. The sensitivity of a parameter was determined based on the t-stat and p-value. The smaller the p-value and larger the absolute value of the t-stat are, the more sensitive the parameter will be, whereas a larger P-value and smaller t-stat indicate less sensitivity for a given watershed. P-values close to zero have a greater significance.

Calibration and Validation of SWAT:

To get the best fit with the Bedessa river outflow, the values for the most sensitive parameters were automatically calibrated using the SWATCUP-2 SUFI-2 method The calibration procedure was completed monthly, continuing half of the statistics obtained until good or better version performance with coefficient of determination, R2 > 0.65, Nash Sutcliff, NS > 0.6 was obtained (Santhi et al., 2001& Moriasi et al., 2007) as showed in Table 2. This was accompanied by a manual adjustment of the parameters to achieve a physically realistic parameter set close to the best fit of the highest quality. After the model parameters were calibrated, the validation for the remaining half of the Bedessa river discharge facts was completed.

SWAT Model Performance:

Model performance can be evaluated by comparing simulated and observed runoff data in terms of mean, standard deviation, maximum daily runoff and total runoff using commonly used indices (Gassman et al., 2006 & Krause et al., 2007). Two statistical indices, coefficient of determination (R2) and Nash-Sutcliffe efficiency (ENS) were used to assess model performance.

$$R^2 = \left[\frac{\sum\left(Q_{obs} - \overline{Q_{obs}}\right)^2 - \sum\left(Q_{sim} - \overline{Q_{sim}}\right)^2}{\left(Q_{obs} - \overline{Q_{obs}}\right)^2} \right] \ldots(2)$$

$$E_{NS} = 1 - \sum \frac{\left(Q_{obs} - \overline{Q_{sim}}\right)^2}{\sum\left(Q_{obs} - \overline{Q_{sim}}\right)} \; X \; 100 \ldots\ldots.(3)$$

Where Qobs denotes the observed discharge and Qsim denotes the simulated discharge, and the bar denotes the mean of the values.

Irrigation land suitability evaluation:

To find suitable land for irrigation, the individual suitability factors of slope, soil, land use, and available irrigation water based on distance from the water source were used as inputs to the irrigation suitability model. The factors were prepared for weighted overlay using GIS Arc Map 10.1; the spatial analysis tool is explained below.

Soil Factor:

Soil is a key factor in determining an area's suitability for agriculture and sustainable irrigation (Dagnenet, 2013 and USDIBR, 2003). For the suitability assessment, soil drainage, texture and

Table 1: The common parameters in SWAT model for sensitivity analysis.

No	Parameter	Definition	Range
1	Alpha_Bf	Base flow alpha factor (days)	0 – 1
2	Gw_Delay	Groundwater delay (days)	0 – 500
3	Gw_Revap	Groundwater "revap" coefficient	0 .02 -0.2
4	Gwqmn	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	0 – 5000
5	Revapmn	Threshold depth of water in the shallow aquifer for "revap" to occur (mm)	0 – 500
6	Ch_K2	Effective hydraulic conductivity (mm/hr)	0 – 500
7	Ch_N2	Manning's n value for main channel	0 - 0.3
8	Epco	Plant water uptake compensation factor	0 – 1
9	Esco	Soil evaporation compensation factor	0 – 1
10	Sol_BD	Soil bulk density	0 – 0.3
11	Sol_Awc	Soil available water capacity	0 – 1
12	Sol_K	Hydraulic conductivity of saturated soil	0 – 2000
13	Sol_Z	Depth from soil surface to bottom layer (mm)	0 – 3500
14	Cn2	Curve number	35 -98
15	Surlag	Runoff delay coefficient	0 – 10
16	Slope	Average slope steepness (m/m)	0 – 999

Table 2: General performance ratings of simulated discharge

		Performance rating		
	Unsatisfactory	**Satisfactory**	**Good**	**Very good**
R^2	<0.5	0.5-0.6	0.6-0.7	0.7-1
NSE	<0.5	0.5-0.65	0.65-0.75	0.75-1

Table 3: Land suitability factor rating for irrigation

Factor	**Factor rating**				**Sources**
	S1	**S2**	**S3**	**S4**	
Slope (%)	0-2	2-5	5-8	>8	FAO (1997) and USDIBR (2003
Soil texture	L–SI CL, C	SIL, SC L, CL	SL	LS, SI–L	FAO 1997
Soil depth (cm)	> 120	90-120	0-90	< 30	(Dagnenet, 2013 and USDIBR, 2003).
Soil Map	Well	Moderat ely	Imperfec tly	Poor	(Dagnenet, 2013 and USDIBR, 2003).
Distance to river (km)	0-1.5	1.5-3	3-5	>5	Seleshi et al., 2016 and Victor et al. 2014
Distance to road (km)	0-3	3-6	6-10	>10	Seleshi et al., 2016 and Victor et al. 2014
LULC	Agricultural/ farm land	Range-grasses	Forest-mixed & range-bush	Barren residential & fores	

Where SIL = silty loam, SCL = silty clay, LS = Loamy Sand, L = Loam, SL = Sandy Loam C = Clay, Cl = Clay Loam, Si = Silt soil depth were extracted from the soil types in the soil map. The soil map has been redefined into four classes that specify suitability of each for surface irrigation (FAO, 2014). The criteria used are given in Table 3.

Slope Factor:

Slope has a direct impact on irrigation methods, susceptibility to erosion, land development, tillage and use of agricultural machinery, design of farm irrigation systems, crop adaptation, and drainage requirements. The dip of the area was calculated using a 20 m resolution DEM and classified in Table 3 into four groups based on the FAO (1997) and USDIBR (2003) classification systems: 0%-2%, 2%-5%, 5%-8% and >8 %.

Distance to Rivers:

One of the basic criteria for determining the suitability of land for surface irrigation is the proximity of the water source (Yalew et al., 2016 and Victor et al., 2014). The main multi-year tributary networks were extracted from the 30 m DEM (Digital Elevation Model) with hydro-processing techniques categorized into four classes in ArcGIS Arc Map 10.1 (0 km-1.5 km, 1.5 km-3 km, 3 km-5km and >5km) in Table 3.

Distance to Roads:

Another important factor in determining the suitability of soil for surface irrigation is the distance to the road (Paul et al., 2020). The road networks were derived from the 30m DEM (Digital Elevation Model) using hydro-processing methods in ArcGIS Arc Map 10.1 in (Yalew et al., 2016 and Victor et al., 2014) in Table 3.

Land Use and Land Cover:

Another important factor used is land use, which was obtained from the Ethiopian mapping agency. The primary land use types found in the study area are farmland, grassland, shrub land, and forest land. Expert judgment was used to divide the land use classes into four categories of suitability (S1, S2, S3, and N). The land cover for different land use in the study watershed is presented in table 9.

Structure of Land suitability classification:

FAO (2007) proposed a method of assessing land suitability in the form of suitability ratings ranging from very suitable to not suitable based on the suitability-of-land characteristics for different crops in Table 4. The general conceptual methodology used throughout the study presented in Fig. 2 and Table 4 shows the weights given to each of the contributing parameters and their classes.

Weighted Overlay Analysis of the Factors:

The weights were developed by providing a series of pairwise comparisons of the relative importance of things to the quality of pixels for the activity being evaluated. The logic developed by a previous study (Saaty et al., 1999) was used to weighting under the AHP with a weighted linear combination. AHP was administered by weighting each parameter, followed by summation of the results to obtain a quality map (Eastman et al., 2001). In pairwise comparison, each factor was matched head-to-head (one-to-one) and a pairwise or comparison matrix was prepared to specify relative importance. An importance scale was scored from 1 to 9 (Table 5). The highest value 9 corresponds to absolute importance and therefore the reciprocal of all scaled ratios within the transpose position (1/9) have been entered showing absolute triviality.

The column factors were compared to the factors in the rows for their significance to surface irrigation, using the rating given in Table 6. After the pairwise comparison matrices were filled, the weights of the factors were calculated by normalizing the respective eigenvector. The cumulative eigenvector and the weight modulus were used to identify the consistency ratio (CR) and to develop the best fitting weights. The CR was calculated according to the methodology proposed by a previous one (Wind et al., 1999).

Irrigation water requirement:

The total amount of water that needs to be supplied by irrigation during the growing season of the plants is called Irrigation Water Demand (Net, IRn). Irrigation water requirement (IWR) was calculated, taking into account the precipitation, P (Punmia et al., 2009). Mathematically, it can be expressed as:

IRn (mm) = ETcrop – Effective rainfall (mm)... (4)

Where IRn is irrigation water demand and ETcrop is the water requirement of the crop.

Gross irrigation water requirements:

Gross irrigation water requirements (GIWR) were calculated from the IWR using an irrigation efficiency (ea) of 65% (FAO, 2001) and a water conveyance efficiency (ec) of 75% (Smith et al., 2000) multiplied by the area irrigated (A) and converting it in units of flow, as follow:

$$GIWR = \frac{IWR}{e_c e_a} A \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (5)$$

Table 4: Land suitability classification

FAO symbol	Suitability	Description
Class S1	S1 (highly suitable)	Land having no significant limitation to sustained application of a given use.
Class S2	S2 (moderately suitable)	Land having limitations which in aggregate are moderately severe for a sustained application of a given use.
Class S3	S3 (marginally suitable)	Land having limitation which in aggregate are severe for a sustained application of a given use and will reduce productivity or benefits.
N	N (Not suitable)	Land with qualities that appear to preclude sustained use of the kind under consideration.

Table 5: Pairwise comparison matrix for with analysis

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

Table 6: The pairwise comparison for irrigation suitability factors

Factors	Soil	LULC	River	Road	Slope
Soil	1	4	1/3	4	1/5
LULC	¼	1	1/5	1/2	1/7
River Proximity	3	5	1	6	1/2
Road Proximity	1/4	2	1/6	1	1/7
Slope	5	7	2	7	1

Table 7: Sensitivity analysis of model parameters based on t_stat and value

Parameter	Description	T_stat	P_Value	Rank
SOL_BD	Moist bulk density	-16.113	0.000	1
GW_DELAY	Ground water delay (Days) Threshold depth of water	7.939	0.000	2
SOL_K	Saturated hydraulic conductivity	-6.632	0.000	3
CN2	SCS_CN for Moisture condition	-5.631	0.000	4
GW_REVAP	Ground water evaporation coefficient	2.246	0.026	5
REVAPMN.	Threshold depth of water in the shallow aquifer for "revap" to occur (mm).	-1.930	0.055	6
SOL_AWC	Available water capacity of the soil layer (Mm/Mm)	1.797	0.073	7
ALPHA_BF	Base Flow Alpha Factor (Days)	1.392	0.165	8
GWQMN (mm)	Threshold depth of water in the shallow aquifer required for return flow to occur	1.227	0.221	9
ESCO	Soil evaporation compensation factor (unit less)	0.065	0.948	10

RESULTS

Sensitivity Analysis, Calibration and Validation:

After sensitivity analysis of the sixteen hydrological parameters in SWAT, 10 flow parameters were found to be sensitive to the SWAT model. The maximally sensitive parameters have been described within the order of magnitude as presented in Table 7.

For the calibration period (1991-2004), the

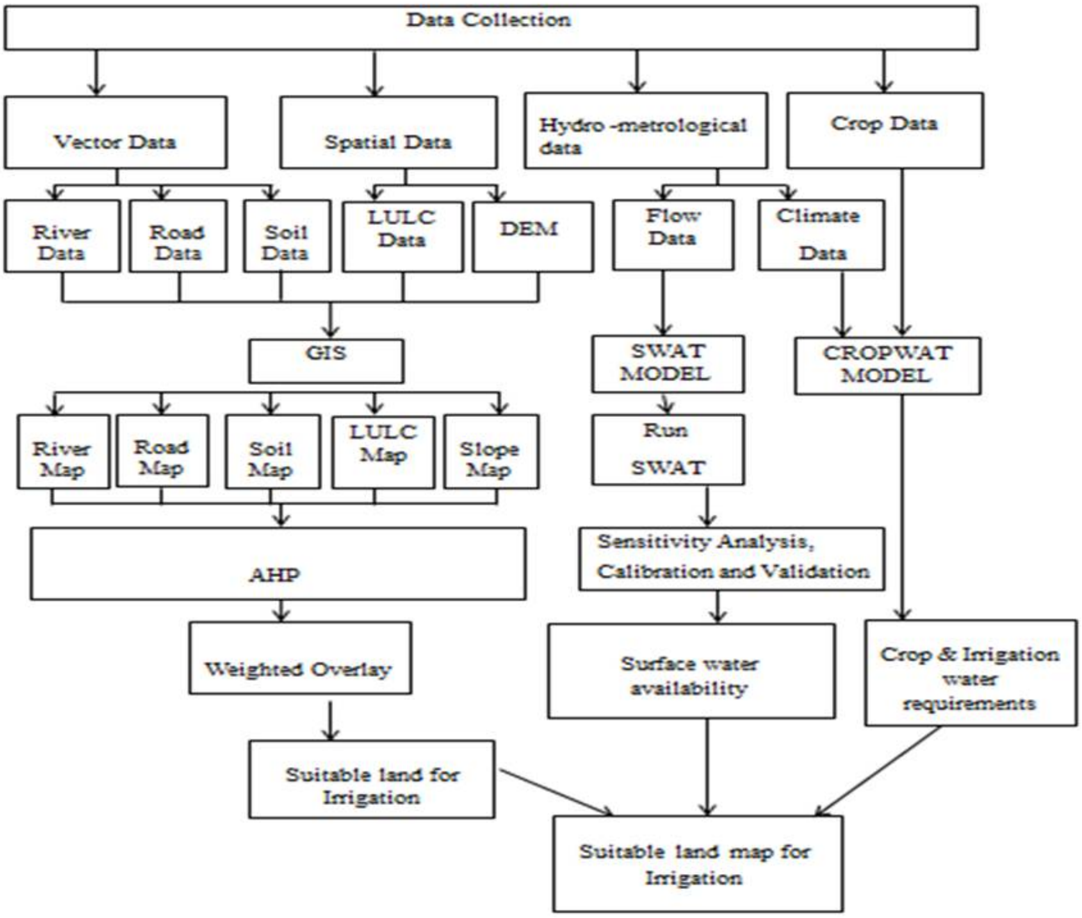

Fig. 2: Conceptual framework adopted for the generation of land suitability for surface irrigation map.

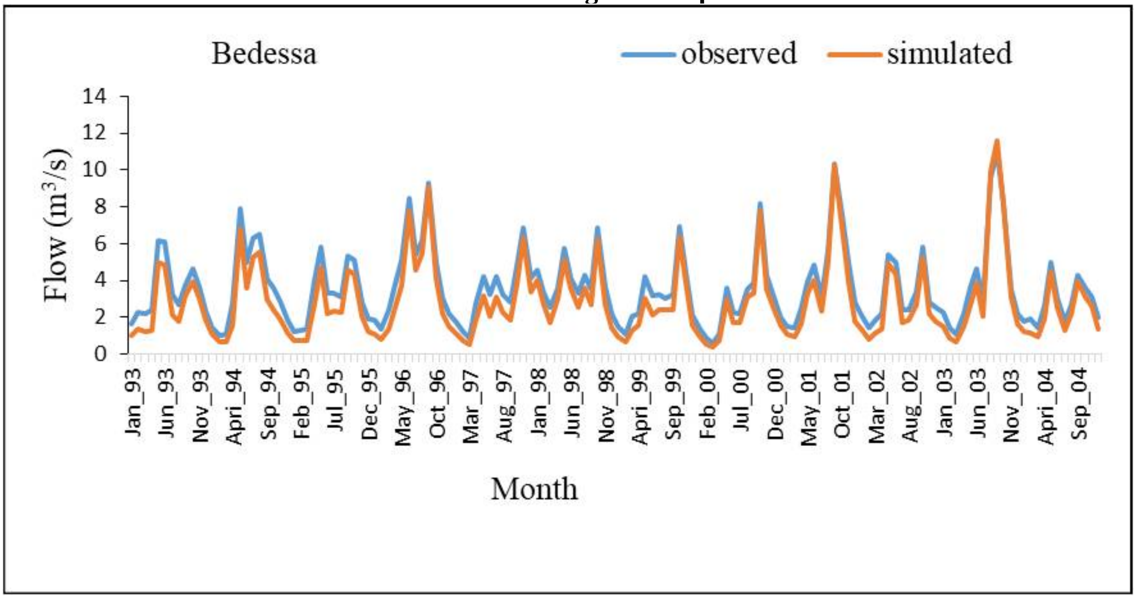

Fig. 3: Simulated versus observed monthly flows in model calibration Bedessa

simulated monthly discharges show very good agreement with the observed monthly discharges in the Bedessa River, with R2 = 0.72 and NS = 0.71 in Table 8 and Fig. 3. There was also good agreement between measured and predicted runoff during the validation period (1994-1996) with R2 = 0.77 and NS = 0.64% as shown in Table 8 and Fig 4.

Assessment of land suitability and identification of suitable areas for surface irrigation

Soil Suitability:

Soil texture, soil drainage and soil are the main physical properties of soil; the result is shown in Table 9. Soil texture suitability is shown in Fig. 5a, drainage suitability map in Fig. 5b, soil depth suitability map in Fig. 5c, and over all soil suitability maps in Fig. 5d.

Slope suitability:

The suitability result showed that 35.07% of the land was highly suitable, 37.93% moderately suitable, 20.82% suitable and most of the study area in terms of 6.18% class not suitable for surface irrigation development, as shown and mapped in Table 9 (Fig. 5e)

Land use/land cover classification:

The reclassified suitability classes of land use land cover of the watershed for the surface irrigation system are shown in Fig. 5f. Based on the land use map of the district, it was found that 78.92% of the study area was suitable for surface irrigation with some limitations which may cost the mitigation of the environment with respect to land use land cover. Only 21.08% of the district could not be used for surface irrigation under irrigation. The result in Table 9 shows suitable class on the map is located almost all part of the river watershed.

Distance to Road:

According to (Yalew et al., 2016 and Victor e al., 2014), irrigation areas should be located as close as possible to rivers and roads to ensure accessibility in terms of labor and movement of both inputs and output. Their suitability rating is shown below in Table 9 and shown in Fig. 5g.

Distance to water resources:

The suitability of the river proximity was based on the subdivision of the river's proximity map, with the closest proximity being rated as very suitable (class S1) and furthest proximity as not suitable (class S4). Fig. 5h and Table 9 show the suitability of river proximity distance based on an equal split.

Weighting of the factors and weighted over the total suitable areas for irrigation:

In this study, five factors (i.e., slope, LULC, soil, distance to river and distance to road) were selected to outline the land suitability map of the study areas. The irrigation potential of the river was determined by weighing slope, LULC, soil, distance to river, and distance to river road. In this study, the result consistency ratio (CR for pairwise comparison matrix) was found to be 0.053, in Table 10; this was less than the maximum allowable value of 0.1, termed consistent pairwise

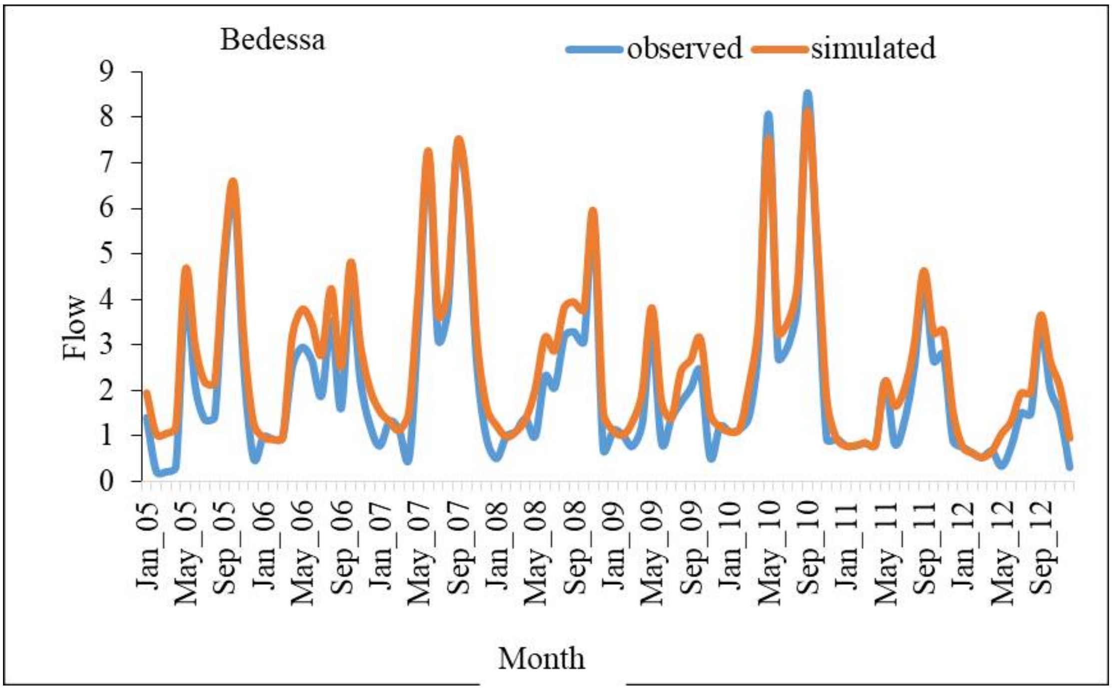

Fig. 4: Simulated versus observed monthly flows in model validation of Bedessa River

comparison, as cited in (Saaty et al., 1999). (Mendoza et al., 2007) recommended and was acceptable for weighting factors evaluating the study area physical land suitability of the Bedessa watershed for the development of an irrigation suitability map, as shown in Fig. 6 and Table 11.

Water availability assessment for surface irrigation:

Surface water availability was determined using SWAT-simulated results of stream flow in the catchment. The mean monthly river water producing a catchment area availability result is 4.39 m3/s to 9.35 m3/s is shown in Table 12.

Gross irrigation water requirement:

The gross irrigation requirement of each selected crop (corn, tomato and cabbage) on irrigable land

Table 8: Summary of model evaluation estimated numerical values

Criteria	Calibration (1993-2004)	Validation (2005-2012)	Performance rating
	Bedessa		
R^2	0.72	0.77	Very good
NSE	0.71	0.64	Satisfactory-Good

Table 9: Factors for surface irrigation land suitability assessment main factor criteria class's suitability local

Criteria	Classes	Suitability	Area coverage	Area coverage (%)
Slope	0%-2%	Highly suitable(S1)	73.39km^2	35.07
	2%-5%	Moderately suitable(S2)	81.55km^2	37.93
	5%-8%	Marginally suitable(S3)	44.75km^2	20.82
	>8%	Not suitable(N)	13.29km^2	6.18
Drainage	Moderately drained	Moderately suitable (S2)	0.78km^2	0.20
	IP(Imperfectly drained)	Marginally suitable(S3)	179.58 km^2	83.67
	P(Poorly drained)	Not suitable(N)	34.68 km^2	16.13
Soil depth	>120m	Highly suitable(S1)	35.41 km^2	16.33
	<30m	Not suitable(N)	179.58 km^2	83.67
Soil texture	Clay	Highly suitable(S1)	35.14km^2	16.33
	Clay loam	Moderately suitable(S2)	179.8km^2	83.67
Over all soil	S1	Highly suitable	0.84ha	0.40
	S2	Moderately suitable	34.83ha	16.20
	S3	Marginally suitable	179.31ha	83.41
LULC	Agricultural land	Highly suitable (S1)	12.00ha	5.57
	Range-grasses	Moderately suitable(S2)	35.26ha	16.40
	Forest-mixed and	Marginally suitable(S3)	122.407ha	56.94
	Residential	Not suitable(N)	45.33ha	21.08
Distance to water	0km-1.5km	Highly suitable(S1)	65.70 km^2	30.56
	1.5 km -3 km	Moderately suitable(S2)	43.53 km^2	20.25
	3 km -5 km	Marginally suitable(S3)	50.21 km^2	23.36
	>5 km	Not suitable(N)	55.54 km^2	23.84
Distance to road	0 km -3 km	Highly suitable(S1)	88.49 km^2	41.16
	3-6 km	Moderately suitable(S2)	57.15 km^2	26.58
	6 km -10 km	Marginally suitable(S3)	39.18 km^2	16.83
	>10 km	Not suitable(N)	30.16 km^2	14.03

Table 10: Pairwise comparison matrix output generated by AHP

Layer name	Soil	LULUC	River proximity	Road Proximity	Slope	Weight %	CI	RI	CR
Soil	1	4	0.3333	4	0.2	14.46	0.0589	1.12	0.0526
LULUC	0.25	1	0.2	0.5	0.1428	4.64	0.0589	1.12	0.0526
River	3	5	1	6	0.5	28.51	0.0589	1.12	0.0526
Road	0.25	2	0.16667	1	0.1428	6.01	0.0589	1.12	0.0526
Slope	5	7	2	7	1	46.35	0.0589	1.12	0.0526
CR								**0.052619**	

Table 11: Overall suitable sites and their area coverage in the sub basin.

S. No	Area (ha)	Area (%)	Suitability class and description
1	389.37	1.81	S1=Most suitable
2	1212.63	5.64	S2=More suitable
3	18666	86.83	S3= Marginally suitable
4	1230	5.72	N=Not suitable
Total	**21498**	**100.00**	

Table 12: Average monthly stream flow results in Bedessa watershed (m^3/s)

Months											
Jan	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
5.07	4.39	5.07	6.88	9.00	7.85	7.21	7.41	8.13	9.35	7.35	5.98

Table 13: Gross irrigation requirements of the selected crops in (m^3/s)

River name	Crop type	Monthly gross irrigation requirement (GIR) m^3s^{-1}					
		Nov	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**
Bedessa	Maize	0.29	0.42	0.68	0.45	0.07	0.00
Bedessa	Tomato	0.19	0.29	0.43	0.30	0.19	0.01
Bedessa	Cabbage	0.15	0.17	0.19	0.22	0.15	0.06
Gross irrigation requirement		0.63	0.88	1.3	0.97	0.41	0.07

Table 14: Summarized monthly flow available and gross irrigation water requirement of potential area

Irrigable area (ha)		Monthly flows & gross irrigation requirement (m^3s^{-1})					
		Nov	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**
1575	Available flow (m^3/s)	7.35	5.98	5.07	4.39	5.07	6.88
	G ross irrigation requirement (m^3/s)	0.63	0.88	1.3	0.97	0.41	0.07

of recognized capacity was predicted using CROPWAT 8.0 software, with each crop following within the area with different area coverage, 45% corn, 30.43% tomato and 23 .90% cabbage of the total irrigable areas in Tables 13 and 14.

DISCUSSION

The SWAT model was used to assess the availability of irrigation water. The sensitivity of the SWAT model parameters was determined for the flow-related parameters (Abbaspour et al., 2007). Before estimating the available water for irrigation, we calibrated and validated the SWAT model using observed watercourses. Table 2 summarizes the model performance based on several statistical criteria. For the calibration period (1993-2004), the simulated monthly stream flows show a "very good" agreement with the observed monthly discharge in the Bedessa river, with R2 = 0.72, and NS = 0.7, Fig. 3). There was also a "good" agreement (Fig. 4) between the measured and predicted discharge during the validation period (2005-2012), with R2 = 0.77 and, NS = 0.64, (Table 8). SUFI-2 proved to be more convenient and easier to use compared to other automatic calibration techniques. The performance of the SWAT model indicates good performance that meets the required criteria (Arnold et al., 2012 and Tobin et al., 2020).

Catchment-level land suitability analysis for surface irrigation is an interdisciplinary approach that incorporates information from various sources such as climate, topography, soils, LULC, and distance from the water source (Luis et al., 2001). Soil is a key factor in determining an area's suitability for agriculture and sustainable irrigation (Dagnenet, 2013 and USDIBR, 2003). Consequently, it could be considered as one of the important factors for delineating the land suitability analysis for surface irrigation (Kassaye et al., 2019 and Getenet et al., 2019). A soil map of the area was created using the Harmonized World Soil Database (FAO/IIASA/ISRIC/ISSCAS/JRC, 2012), including 10 soil types according to FAO 90 nomenclatures. It mainly affects production capacity, but can also affect production and development costs. The results of soil suitability in the weighted overlay analysis showed that approximately 0.40%, 16.20% and 83.41% of the soils in the watershed were classified as strong, moderate and marginal, respectively, with the combined effect of the three gridded soils (drainage, depth and texture) suitability classes.

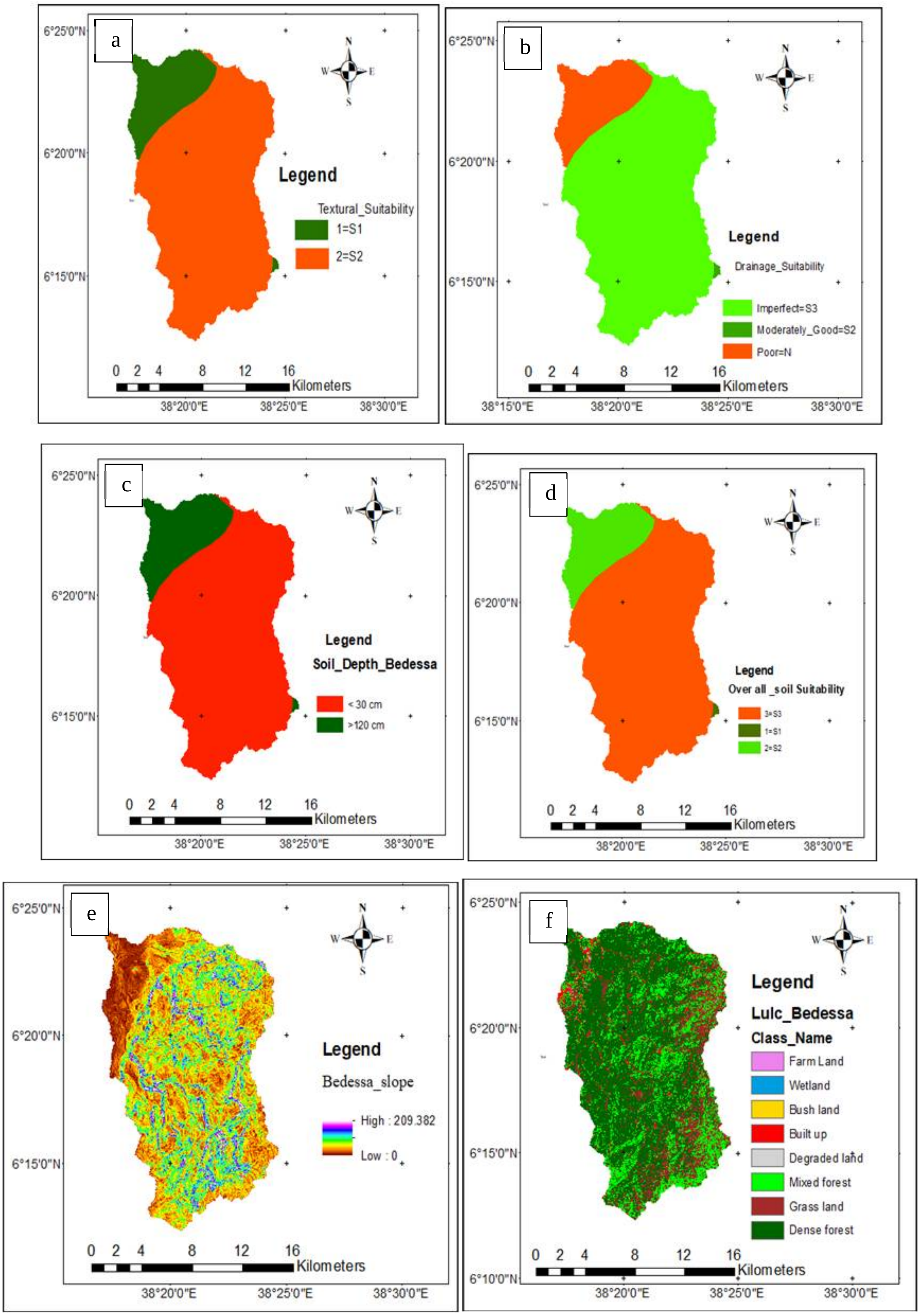

Fig. 5: Suitability maps for Bedessa River in Ethiopia: (a) soil texture (b) soil depth (c) drainage (d) overall soil (e) slope (f) land use and cover

Slope inclination directly influence precipitation infiltration, surface water flow, land tillage and could be considered as some indicators of land suitability for surface irrigation (Abraham et al., 2013). Ninety- four percent of the district (covering of 1144 km2) had slopes of less than 8% and were suitable for surface irrigation systems according to FAO standard guidelines(FAO, 204);

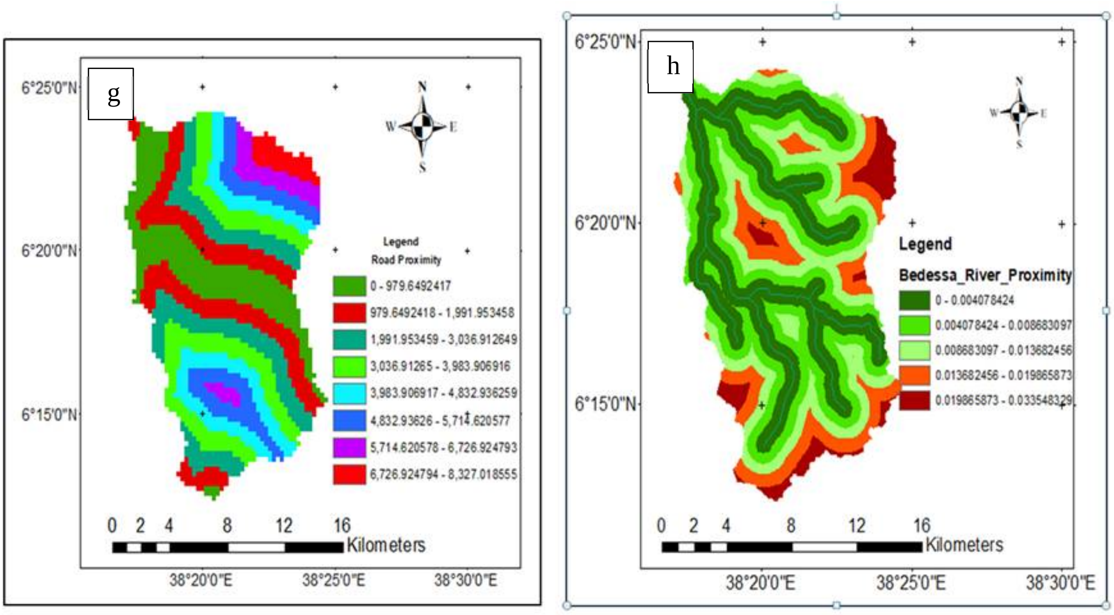

Fig. 6: Suitability maps for Bedessa River in Ethiopia: (g) Road proximity (h) River proximity

the remaining 6 % of the district with slopes greater than 8% were not suitable (Fig. 5e).

LULC includes the type of soil deposits, distribution of settlement areas, water bodies, and vegetation cover within a given area. It is an important factor affecting surface water recharge, land suitability occurrence and availability (Hussein et al., 2016; Kumi et al., 2016; & Hsin-Fu, 2016). The reclassified land cover catchment land use suitability categories for surface irrigation system are shown in Fig. 5f. Based on the land use map of the district, it was found that 78.92% of the study area is suitable for surface irrigation with some limitations that may cost environmental mitigation in terms of land use; only 21.08% of the area under irrigation is not available for surface irrigation. The result in Table 9 shows suitable class on the map is located almost all part of the river watershed.

The distance between irrigable land and water resources and rivers in the study area ranges from 0 km to 5 km (Yonas et al., 2022; Kassa et al., 2019 & Sintaeyhuet et al., 2022). Irrigated areas should be as close as possible to rivers or other water sources; the result is shown in Fig. 5. To use a selected river basin and monthly simulated flow time series, flow duration analyses were carried out to determine how much water is reliably available to be extracted from the rivers for agriculture. The catchment's river flow was simulated using SWAT, and the results were used to calculate the surface water availability. The outcome reveals a range of mean monthly river flow values between 4.39 m3/s and 9.35m3/s. The result of the annually available surface water in the sub-catchment is 5.98m3/s. The amount of water available can irrigate the accessible arable land depending on the annual water supply and demand. Thus, as indicated in Table 11, the district's potential for irrigable land is not constrained by the availability of water resources.

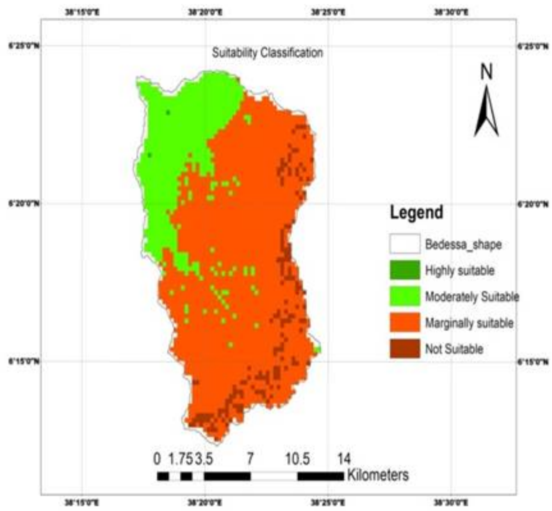

Fig. 7: Land suitability map of the study area

In conclusion, the factors that affect soil suitability are complex and varied, and the factors for each element are also different. Remote sensing provides a fast and reliable technique for detecting factors quickly and reliably. Here, a multifactorial land suitability assessment technique has been studied, which can provide theoretical support for the rational use of land and water resources and the sustainable improvement of agriculture. The version of AHP examined in this paper can overcome the vagueness and subjectivity inherent in different strategies and models. The final result of the suitability assessment by weighted overlay of the gridded maps of the land suitability parameters revealed that the studied area contained approximately 1.81% (389.37 ha), 5.64% (1212.63 ha), 86.83% (18666 ha) and 5.72% (1230 ha) of most suitable, more suitable, marginally suitable and not suitable for irrigation, respectively. The irrigation water requirements of the corn, cabbage and tomato plants were calculated. The irrigation needs of the irrigable land for each catchment area were evaluated with simulated river flows, confirming that the existing water resource capacity should irrigate and satisfy a portion of the total suitable irrigable land in the district. This means the area had sufficient proximity to water resources and roads. Accordingly, a quantitative investigation of chemical properties of land is recommended for future study as it will aid in giving empirical evidence of the land suitability for an area.

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