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Land Suitability Evaluation for Surface Irrigation Using ARC GIS and AHP Techniques in Bedessa, Ethiopia †

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Abstract: The objective of this paper is to the potential application of weighted index overlay analysis for assessing land suitability evaluation for surface irrigation at Bedessa watershed, Ethiopia using geographic information system (GIS) and AHP technique. To identify potential irrigable land, irrigation suitability five factors such as soil, slope, land use/land cover, river proximity and road proximity were taken into account. By weighing values of these constraint irrigation factor data sets by using AHP tool in Arc GIS, resulted from these analysis irrigation suitability maps was developed and potential irrigation land for irrigation was as 1.81%, 5.64% 86.83%, and 5.72% for S1, S2, S3, and N respectively. Based on the data from meteorological station, the irrigation water requirement was calculated using FAO-Penman-Monteith methods. By using Crop Wat version 8.0 model, the irrigation requirement of the selected crops was calculated and the result implies that irrigation water requirement was higher at driest months of the year. In conclusion Potential irrigable land was drawn by comparing the gross irrigation demand of identified irrigable land with respect to available monthly river flow. As a result, the map generated using this platform could be used as a preliminary reference in selecting suitable sites for irrigation in the area..

Keywords: ArcGIS; irrigation potential; land suitability; slope suitability; water availability

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1. Introduction

Agriculture in Ethiopia is dominated by rainfed agriculture. However, rainfall distribution and intensity vary spatially, tending to decrease from southwest to northeast (Cheung et al., 2008). Rainfall also varies temporally resulting in incidents of drought every 4-5 years (Osman and Sauerborn, 2008). These rainfall patterns affect crop and livestock production and contribute to volatility in food prices, which ultimately affects overall economic development (FAO, 2015).

The development of irrigation and agricultural water management holds significant potential to improve productivity and reduce vulnerability to climactic volatility in any country. Ethiopia receives about 980 billion cubic meters (m^3) of rain a year and its agricultural system does not yet get fully benefit from the technologies of water management and irrigation (Seleshi, 2010).

The process of land suitability classification is the evaluation and grouping of specific areas of land in terms of their suitability for a defined use. The suitability defines the level of the crop requirement with respect to the present soil/land characteristics. Matching the land characteristics with the factor ratings resulted in defining the suitability classes. Hence, suitability is a measure of how well the qualities of a land unit match with requirements of a particular form of land use (FAO, 2003). Interpreting soil qualities and site information for the agriculture use and management practices is integrated using GIS (FAO, 1991 and FAO, 2007). In agricultural context, finding optimal locations for crops can increase economic benefits, as well as reduce negative environmental consequences.

Proper recognition of land abilities and allocation of them to the best and most profitable and stable revenue operation system has special importance for preventing ecosystem structure destruction. With the increase of demand for land, land evaluation has become more important as people strive to make better use of the limited land resources. Because, it is the process of assessment land performance for specified purposes (Rossiter, 1996; Collins et al., 2001).

Recently, various studies have been applied using weighted overlay analysis for assessing Land suitable analysis for irrigation (Haile Gebrie and Meron, 2007; Kebede 2010; Gizachew 2014, Negash. W. 2004; & Dagnenet 2013). Among many determinant factors of the land suitability determination for irrigation topography, slope, soil type, land cover/land use, water source drainage, soil texture, Soil depth, electrical conductivity of soil solution, calcium content, organic matter and climatic factor can be listed as examples Suitability analysis is the process and procedures used to establish the suitability of a system according to the needs of a stakeholder. Urban development and migration to urban areas are global phenomena. Thus, many small cities and isolated populations are rapidly changing into large metropolitan cities (Kamal Jain and Y. Venkata Subbaiah et.al; 2007). This rapid increase of urban population causes high level impact on the urban environment and creates many problems such as unplanned sprawl, inadequate housing facilities, traffic congestion, insufficient drainage, sewerage problem and lack of other amenities (Liu, 1998) Hence, the factors and the development activity in the area and they used different per researches, and consequently, the results vary (Steiner and McSherry, 2000).

The estimates of the irrigation potential of Ethiopia vary from one source to the other, due to lack of standard or agreed criteria for estimating irrigation potential in the country. According to Awulachew, (2010), the cultivable land area varies from 30 to 70 Mha. He estimated that the total irrigable land potential in Ethiopia is about 5.3 Mha assuming use of existing technologies, including 3.7 Mha from gravity-fed surface water, 1.1 Mha from ground water and 0.5 Mha from rainwater harvesting. Most of these statistics are derived by adding up the irrigation potential of the country's 12 river basins. Specifically, in Bedessa watershed area, suitable area for further development or evaluation of land suitability for irrigation purpose becomes more important in the area is scarce and those available are not developed well.

Under the present situation, where land is a limiting factor, it is impractical to bring more area under cultivation to satisfy the ever-growing food demand (Fischer et al., 2002). So, the practical development of the Land suitability assessment for irrigation will have a significant effect on the improvement of the community livelihood in the study area as well as the country. Accordingly, this paper contributes by providing delineated Land suitability analysis through implementing remote sensing techniques ARC GIS and AHP tools to have proper administration, management, and sustainable use by identifying suitable land for irrigation purpose in the area. Five determinant factors, namely, land cover, slope, soil Drainage distance from water supply, were accounted for in the study.

2. Study Area

The study was conducted in Bedessa river catchment of Gedio zone, SNNPR state and Abaya Woreda, Oromia regional State. The Bedessa river catchment is geographically located between 6°11′–6°24′ North latitude and 38°16′–38°24′ East longitude. It is located at 361 km south of Addis Ababa and 92 km from capital of the regional sate, Hawassa and 2 km from Dilla town. Its elevation ranges between 1449–3029 m.a.s.l. The climate is highly variable in the river catchment In the highlands and escarpment bounding the rift floor, rainfall exceeds 1600 mm/year, whilst the lowest elevation which receives much less rainfall, often below 800 mm/year. According to MoA (2000) classification, agro-ecology of Ethiopia is classified as: Wurch, Dega, Weyna-dega, Kolla, and Bereha. Both rainfed and traditional irrigation agriculture have been practiced within the watershed and from these maize and tomato are the two major crops that have been produced using small scale surface irrigation.

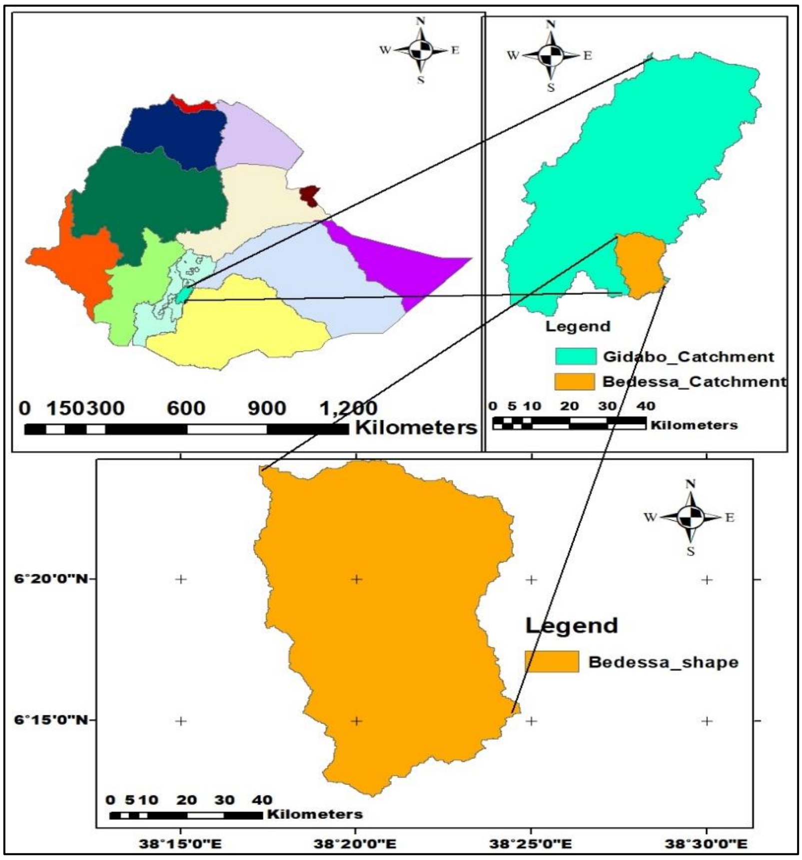

Figure 1. The geographical location of Bedessa Watershed.

3. Materials and Methods

In this study, various types of data and software have been used. The data required for this particular study includes climate data; soil and land use the land cover map. The required meteorological data such as all climate data were collected from the National Meteorological Agency (NMA) of Ethiopia used as input in CROPWAT software. Whereas, Soil and land use data were obtained from the Ethiopian Ministry of Water, Irrigation and Electricity (EMWIE) reference evapotranspiration (ETo): CROPWAT 8.0 computer program was used to estimate the total water requirements of major crops grown in the study area. This program uses the Penman-Monteith equation to calculate reference evapotranspiration (ETo). the potential land suitable for irrigation using surface water was estimated by the Weighted Overlay tool of ArcGIS Spatial Analyst Toolbox based on multi-Criteria Evaluation decision (MCE) techniques. The land suitability was evaluated by developing and assigning weight to the key factors that affect the irrigation potential of the land from Surface water potential. The factors considered under this study were a LULC, soil types and slope derived from DEM of the sub-river basin), climate characteristics, river proximity and Road proximity. Finally, the reclassified and weighted factor maps are overlain and a preliminary surface irrigation area suitability map is computed by the Weighted Overlay tool of ArcGIS Spatial Analyst Toolbox. In general, the study procedure adopted was shown in the flowchart below Figure 2.

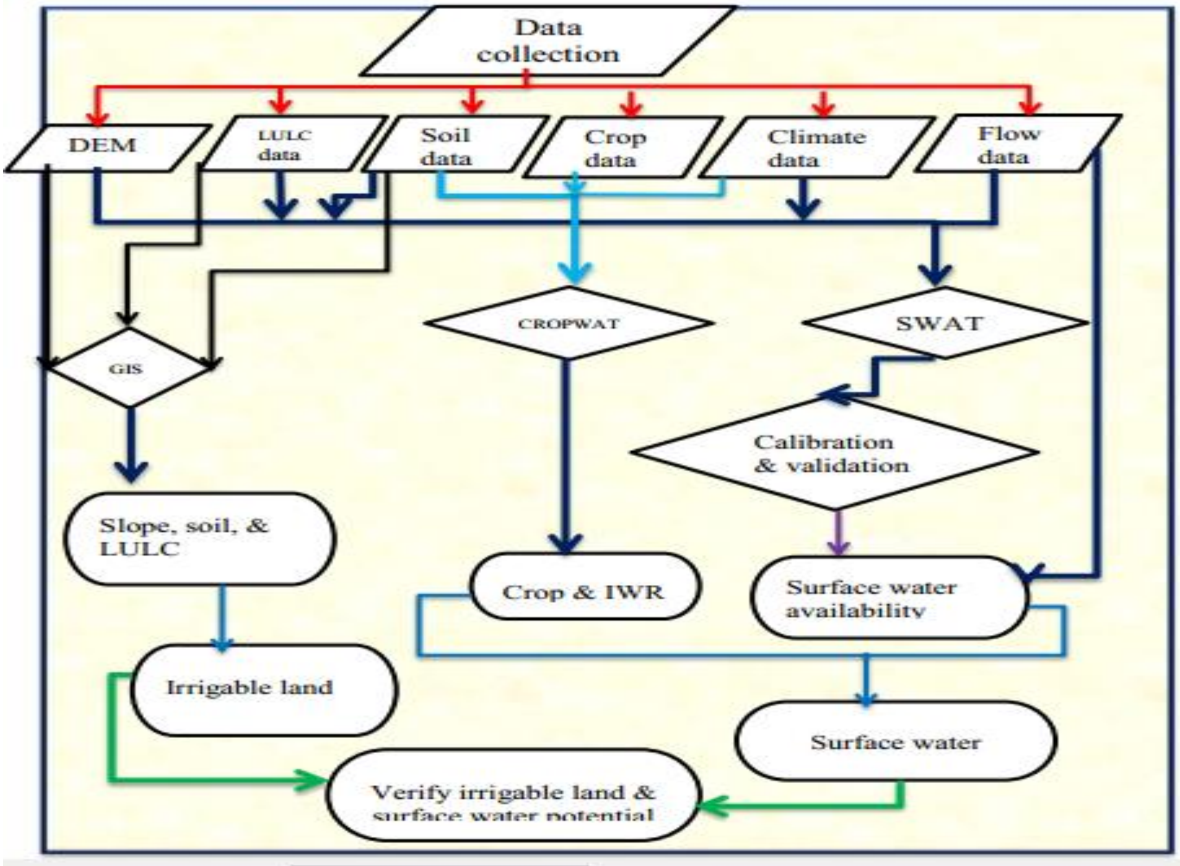

Figure 2. Flow chart of Suitable land analysis for surface irrigation.

4. Results and Discussion

4.1. Suitability Analysis for the Surface Irrigation Land in Bedessa Watershed

4.1.1. Slope Suitability

According to the slope classification result, the land having slope range below 2 % was classified as highly suitable while the slope range > 8% categorized as unsuitable class for surface irrigation. This type of land classification is very common and widely used in many researches and also recommended by FAO guidelines (FAO, 1976 and 1996).

The suitability result indicated that 35.07% of the land was highly suitable, 37.93 % moderately suitable, 20.82% marginally suitable and majority of the study area in terms of slope 6.18% was not suitable class for surface irrigation development.

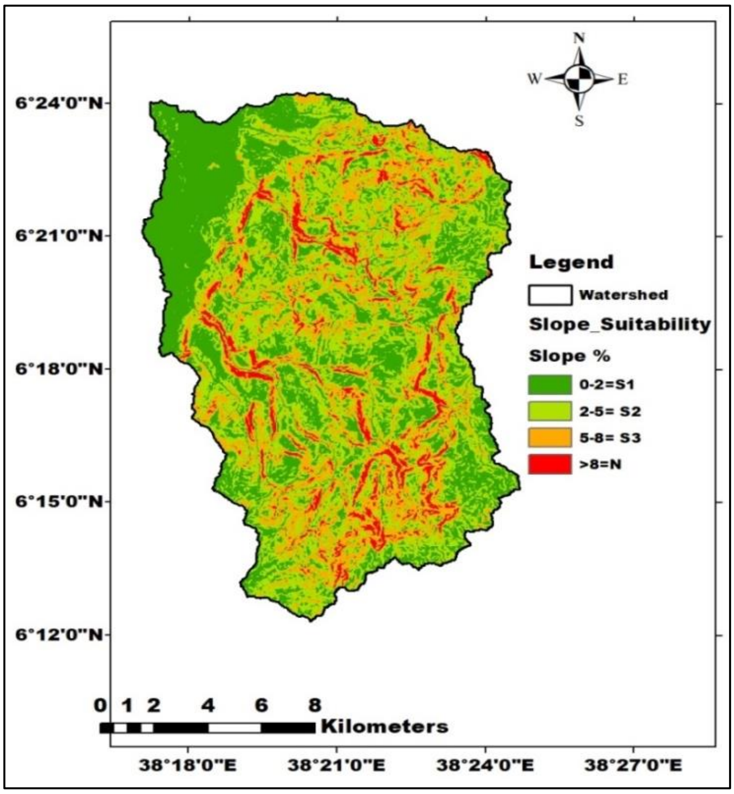

Figure 3. Map showing the suitability of Bedessa Watershed based on slope.

As shown in the Table 1 most of the catchment area is suitable for the development of surface irrigation and it covers 73 % (154.94 km²), of the total area. The remaining 27% (58.04 km²) of area is not suitable for surface irrigation development.

Table 1. Slope suitability range of the Bedessa Watershed for surface irrigation.

Slope Range (%)	Weight	Area (Km²)	%	Description
0-2	1	73.39	35.07	Highly suitable (S1)
2.0001-5	2	81.55	37.93	Moderately suitable (S2)
5.0001-8	3	44.75	20.82	Marginally suitable (S3)
>8	4	13.29	6.18	Not suitable (N)
Total		214.98	100	

Source FAO (1996), Slope suitability classification for surface irrigation.

4.1.2. Soil Suitability

Selection of suitable method of irrigation for particular soil type and terrain features is a key prerequisite for sustainable irrigation system (Negash, 2004). Physical properties of the soil as well as climatic data are the major factors that determine the land suitability of a given land. The land suitability of the river catchment with regard to soil has been for different LUTs of the study area with soil texture, depth and soil drainage (Fasina et al., 2008) in (Table 2). The assessment of soils for irrigation involves using properties that are permanent in nature that cannot be changed or modified. Such properties include soil texture, depth and soil drainage study area in Figures 4–6 an overall soil suitability map in Figure 7.

Table 2. Land use/land cover, SWAT codes and their areal coverage in the watershed.

Land Uses	SWAT Code	Area(km²)	% In Watershed Area	Rate
Forest-Evergreen	FRSE	41.46	19.29	N = 4

Forest-Mixed	FRST	122.167	56.83	S3 = 3
Range-Bush	RNGB	0.24	0.11	S3 = 3
Range-Grasses	RNGE	35.26	16.40	S2 = 2
Agricultural/farm Land	AGRL	12.00	5.57	S1 = 1
Residential	URBN	3.80	1.76	N = 4
Barren	BARR	0.07	0.03	N = 4
Total		**214.98**	**100**	

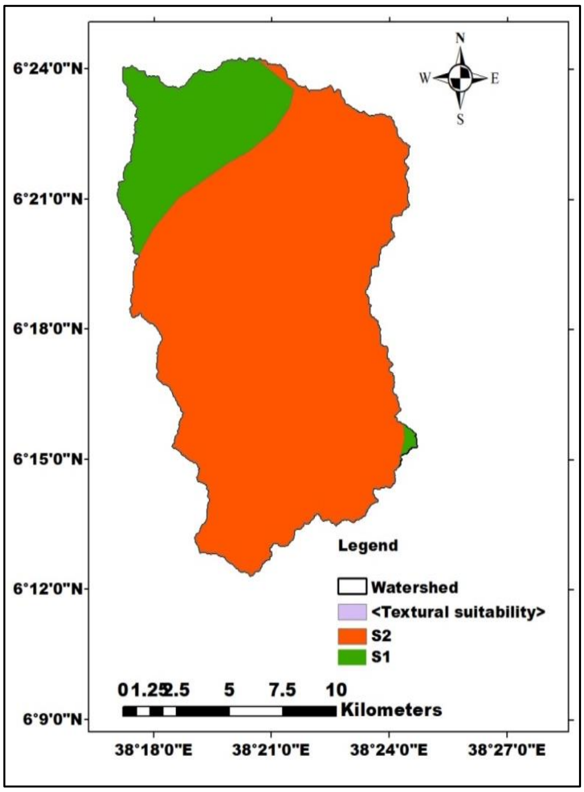

Figure 4. Soil texture suitability of study area.

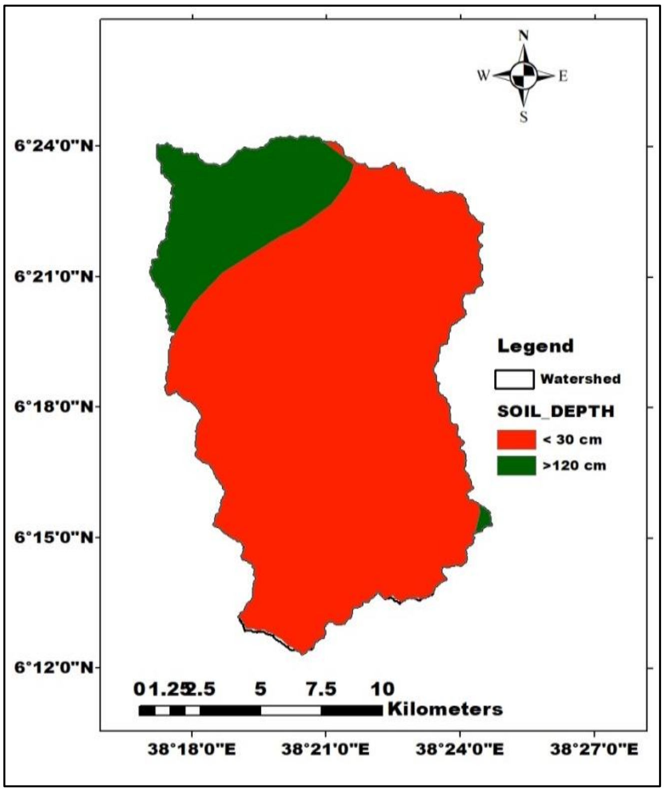

Figure 5. Soil depth suitability of study area.

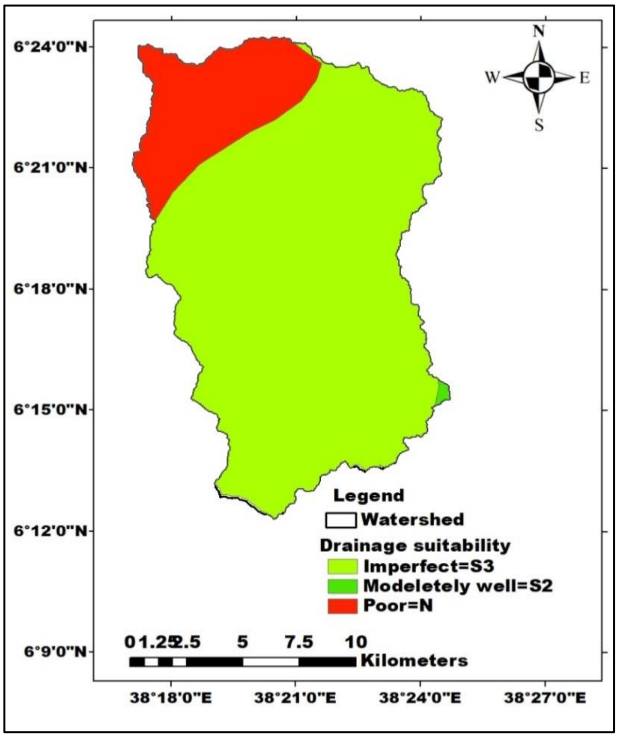

Figure 6. soil drainage suitability classification.

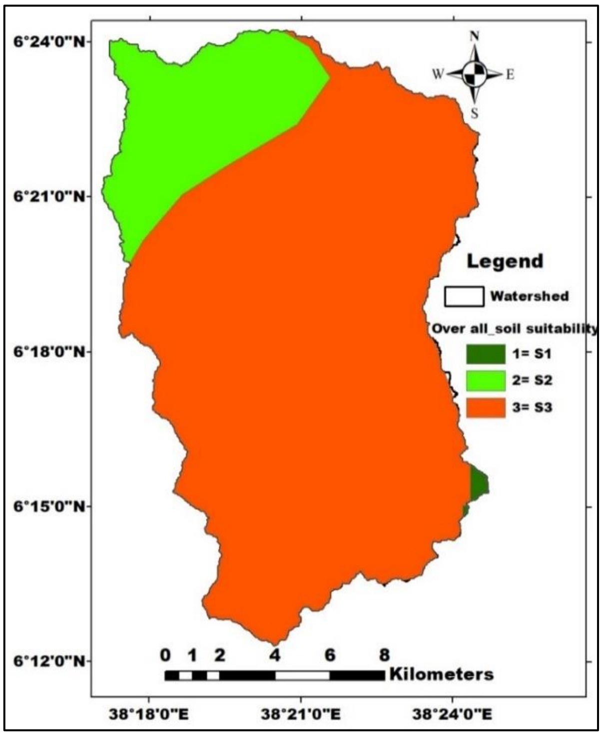

Figure 7. Over all soil suitability Map.

4.1.3. Land Use/Cover Suitability Investigation

Land use is defined as the human function of a given area (Paulati et al., 2005; ALUM, 2011) and is needed to develop effective assessment of local and regional planning and to respond to natural resource management problems (Ross and Easley, 2002; ALUM, 2011). Based on the fact that existing land use is a major part of the foundation upon which land use policies and future land use maps are built (Ross and Easley, 2002), current land uses are considered when evaluating existing condition.

LULC map of the watershed was derived from satellite image. The image was used only to develop the LULC map of the Bedssa watershed. LULC influences on the cost of irrigation practice to prepare the land for agriculture. 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).

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 2) and Figure (8).

From the Table 2 the land use/cover suitability analysis was classified as highly, moderately, marginally and not suitable classes for irrigation.

The land use/cover type such as farmland was classified as highly suitable for irrigation. It covers 5.57 % of the total area of the watershed. Moderately suitable class includes grass land which cover accounts 16.40 % of the area, bush land and mixed forest are categorized under marginally suitable and other land cover types such as settlement, barren land, water body and dense forest land covers were categorized under not suitable for irrigation, it covers 56.94 % and 21.08 % respectively of the total size of the study area Table 2.

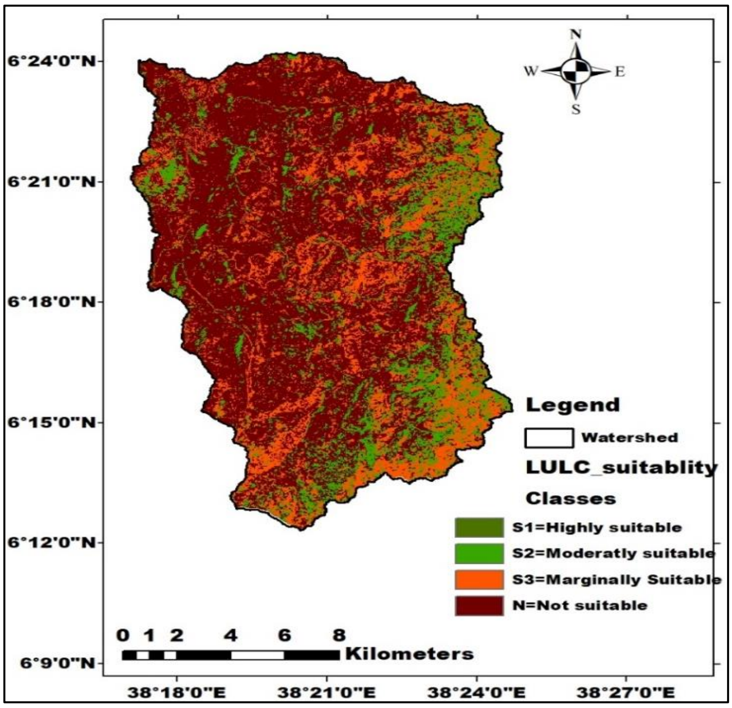

Figure 8. LULC classification.

4.2. Weight Assignment to Parameters

The results in Table 3 show that the factor "slope" is the most important factor since all its values are greater than 1 in its row followed by "river proximity" that only has one value less than 1. The least important factor in considering surface water irrigation suitability is "road proximity" with all its row values less than 1 except 2. The judgment is subjective, weighting of decision factors is determined based on the importance of each factor and involves knowledge of those familiar with irrigation in the area. The factors slope, river proximity and soil were judged as very important because slope and river proximity are associated with a large initial investment and the remaining were considered were considered as important to least important.

Table 3. The pairwise comparison for irrigation suitability factors.

Factors	Soil	LULC	River	Road	Slope	Weight
Soil	1	4	1/3	4	1/5	0.144563
LULC	¼	1	1/5	1/2	1/7	0.046389
River Proximity	3	5	1	6	1/2	0.285071
Road Proximity	1/4	2	1/6	1	1/7	0.060519
Slope	5	7	2	7	1	0.463457

The next step of AHP pairwise comparison is to normalize the matrix. This is performed by dividing each cell value by the sum of its column. The normalized values of each row are then averaged to produce the priority vector. These priority vectors indicate the final weights of the variables.

Table 4. Normalized score table.

Factors	Soil	LULC	River Proximity	Road Proximity	Slope	Weight	%
Soil	0.105263	0.210526	0.09009	0.216216	0.100719	0.14456	14.46
LULC	0.026316	0.052632	0.054054	0.027027	0.251799	0.04639	4.64

River proximity	0.315789	0.263158	0.270270	0.324324	0.251799	0.28507	28.51
Road proximity	0.026316	0.105263	0.045045	0.054054	0.071942	0.06052	6.01
Slope	0.526316	0.368421	0.540541	0.378378	0.503597	0.46346	46.35
Sum	1	1	1	1	1	100	

According to Table 9; the maximum weight is given to the slope of the area because if it is too steep it incurs high cost to level the land and also the water cannot easily flow to the downward unless electrical system is used.

Table 5. Pair-wise 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	0.058933	1.12	0.052619
LULUC	0.25	1	0.2	0.5	0.1428	4.64	0.058933	1.12	0.052619
River proximity	3	5	1	6	0.5	28.51	0.058933	1.12	0.052619
Road proximity	0.25	2	0.16667	1	0.1428	6.01	0.058933	1.12	0.052619
Slope	5	7	2	7	1	46.35	0.058933	1.12	0.052619
Average CR									**0.052619**

4.3. Delineation of Land Suitability Map for the Bedessa Watershed

As it is shown in the Table 10, the CR value is 0.053 which is less the maximum allowable recommended Saaty's value (0.1). Since it is less than 0.1 the consistency ratio is accepted. According to Saaty's technique, all the five factors, which were selected for the evaluation of irrigation potential in the basin, were weighted using pair wise comparison. After the pair wise comparison matrices were filled, the weight module was used to identify consistency ratio and develop the best-fit weights. The consistency ratio (CR) was found 0.053, this was less than the maximum allowable 0.1, which was said to be consistent pair wise comparison as recommended in (Saaty, 1990) cited in Mendoza *et al.* (2008) and was acceptable for weighting the factors to evaluate the physical land capability of the Bedessa watershed for developing irrigation suitability map.

As it can be seen in Figure 9, the weighted overlay analysis result was shown and tabulated in the Table 6.

Table 6. 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 = Less suitable
4	1230	5.72	N = Not suitable
Total	**21498**	**100.00**	

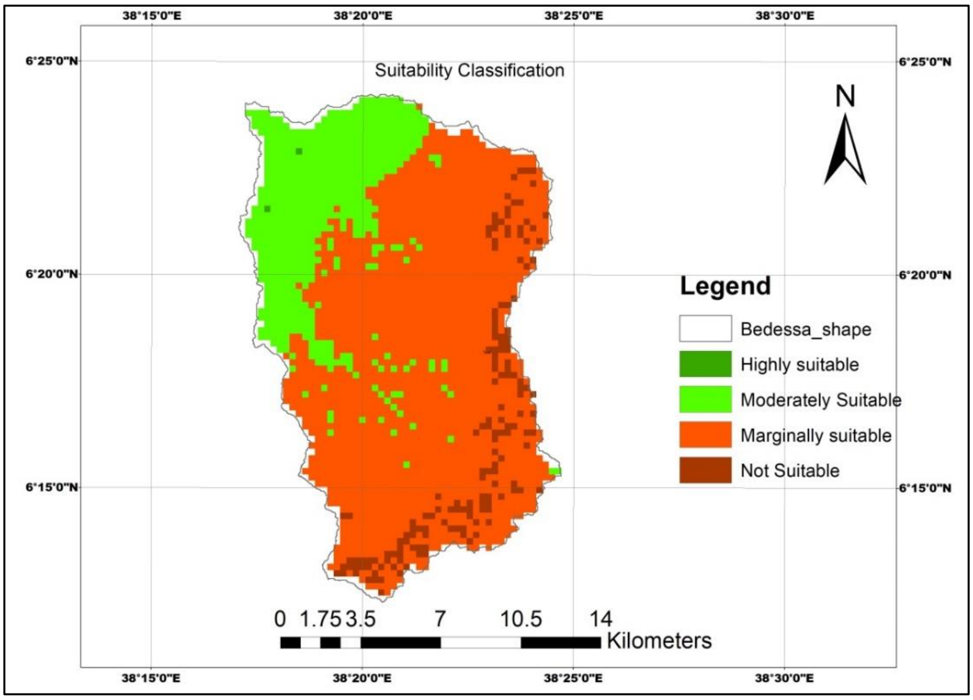

Figure 9. Final suitability land map of Bedessa river catchment.

Generally, the result of suitability analysis through weighted overlay of the rasterized maps of the land suitability parameters revealed that about 1.81% (389.37 ha), 5.64 % (1212.63 ha), 86.83% (18666 ha) of land in the study area were in the ranges of highly to marginally suitable classes respectively and 5.72 % (1230 ha) of the area categorized under not suitable class which was presented in Table 6.

Based on the suitability analysis 1575 hectares of land is potentially suitable for surface irrigation development and most of the area is marginally/less suitable.

4.4. Water Availability Assessment for Surface Irrigation

Surface water availability has been identified from the SWAT simulated outputs of stream flow of the watershed. The mean monthly surface water flow availability results of the watershed produce approximately from 4.39 m^3/s to 9.35 m^3/s.

Table 7. Average monthly stream flow results in bedessa watershed (m^3/s).

Months											
Jan	**Feb**	**Mar**	**April**	**May**	**Jun**	**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

4.5. Sensitivity Analysis of SWAT Parameters

Parameter sensitivity analysis was done in order to determine the key parameters that are needed for calibration. Ten calibration parameters that affect flow were used in the sensitivity analysis Table 8. Global sensitivity analysis method was used and the parameters that were found to be most sensitive were used in the calibration process. The t-stat is a measure of sensitivity where larger in absolute values are more sensitive. The p-value determines the significance of sensitivity where values close to zero are more significant (Abbaspour, 2007). According to the results obtained from the sensitivity analysis, the parameters were ranked depending on the values of t_ stat and p_value.

Table 8. Sensitivity analysis of model parameters based on t_stat and p_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

The result of the sensitivity analysis showed that 10 flow parameters were sensitive to the SWAT model. The most sensitive parameters were described in the rank order as they can be presented in Table 8. The parameters, SOL_BD, GW_REVAP, SOL_K, CN2, were identified to be highly sensitive. However, REVAPMN, SOL_AWC were identified as medium sensitive parameters. The remaining four parameters ALPHA_BF, GWQMN, GW_DELAY and ESCO were lower sensitive parameters

4.5.1. Arc SWAT Model Calibration Result

Measured flow data of twelve years from the period 1 January 1993 to 31 December 2004 were used for calibration and observed versus Simulated monthly flows in model calibration at monitoring point is shown below in the Figure 10 for river Bedessa.

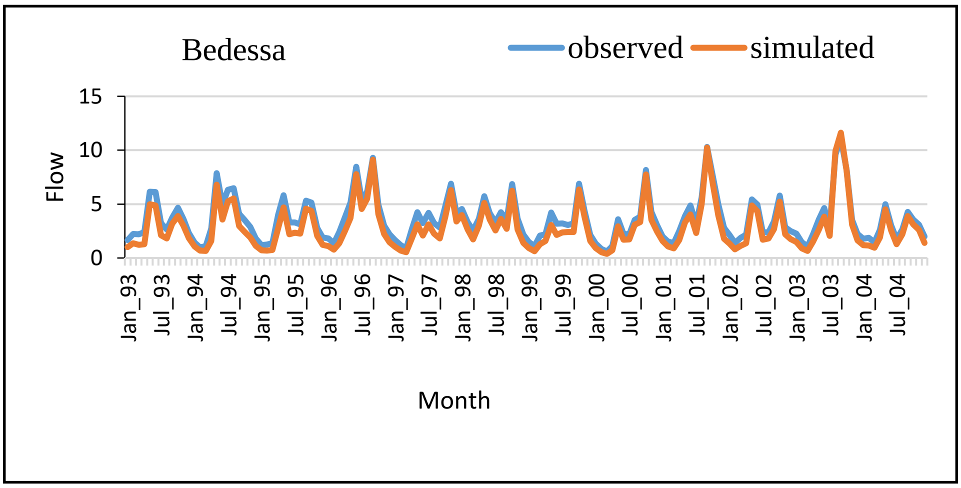

Figure 10. Simulated versus observed monthly flows in model calibration Bedessa.

The model was calibrated using monthly time step data of twelve years. As the model calibration result shown in Figures 10, there are some under and over estimations in the model output in some points but the overall result assured that the simulated flow is good to very good correlated with the measured/observed data with ($R^2 = 0.72$), and (ENS = 0.71) which shows the best performance of the model.

4.5.2. Validation

As model calibration is not enough to say the model output is representing the study area, it has to be validated using an independent dataset. Therefore, it was validated using monthly time step isolated data to check its reliability. The model validation result shows that there are some under and over estimations in the model output as compared to the measured data but the overall validation result evidences there is a good correlation between the simulated model output and observed/measured data. Based on the model performance evaluation parameter numerical values of determination coefficient (R^2), and Nash-Sutcliff's simulation efficiency (ENS) assured that the model shown a good performance during validation so as to able to simulate the runoff in the study area.

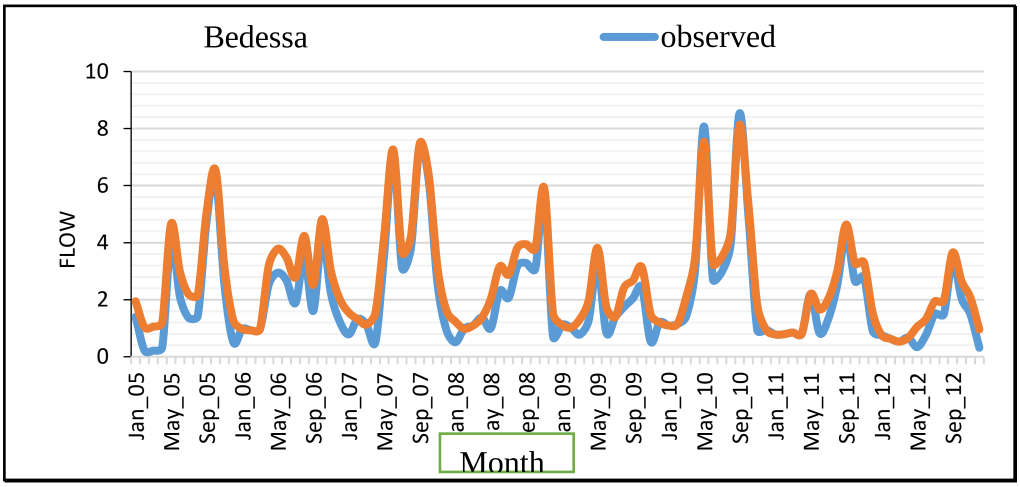

Figure 11. Simulated versus observed monthly flows in model validation of Bedessa River.

The model performance evaluation parameters determination coefficient (R^2), and Nash Sutcliff's simulation efficiency (NSE) with their allowable range and estimated numerical values during model calibration and validation are summarized in Table 14, below.

Table 9. 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

4.6. Gross Irrigation Water Requirement

Gross irrigation requirements of each selected crops (Maize, Tomato and Cabbage) at identified potential irrigable lands were estimated using CROPWAT8.0 software. Each crop adopted in the area various in areal coverage, 45 % of Maize, 30.43% of Tomato and 23.90% of cabbage of the total irrigable sites. Table 15, describes monthly gross irrigation water requirements of Tomato and Maize resulted from monthly water demands of the full growth stage of Tomato and Maize that should be abstracted from the local cropping period.

Table 10. Gross irrigation requirements of the selected crops in (m^3/s).

Bedessa Watershed	Irrigable Area (ha)	Crop Type	Monthly Gross Irrigation Requirement (GIR) m³/s											
			January	February	March	April	May	June	July	August	September	October	November	December
	1575	Maize	0.68	0.45	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.42
		Tomato	0.43	0.30	0.19	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.29
		Cabbage	0.19	0.22	0.15	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.17
Total Gross Water Requirement			1.3	0.97	0.41	0.07	0	0	0	0	0	0	0.63	0.88

Table 11. Summarized monthly flow available and gross irrigation water requirement of potential area.

Irrigable Area (ha)	Flow &GIR of Major Crops	Monthly Flows Available in Catchment & Gross Irrigation Requirement (GIR)											
		January	February	March	April	May	June	July	August	September	October	November	December
1575	Available flow(m^3/s)	5.07	4.39	5.07	6.88	9.00	7.85	7.21	7.41	8.13	9.35	7.35	5.98
	GIR (m^3/s)	1.3	0.97	0.41	0.07	0	0	0	0	0	0	0.63	0.88

5. Discussion

The assessment of irrigation suitability Bedessa sub basin was conducted in Gedeo Zone, SNNPRS region. The watershed area was found to be 21498 ha. Factors which were considered to evaluate irrigation land suitability were soil, slope, land use/cover, river and road proximity. Irrigation land suitability was evaluated based on FAO guideline such as S1, S2, S3 and N. Based on the analysis, 93.82 % of slope, 99 % of soil, and 78.91% of land use /cover of the study area were identified to be in the range of highly suitable to marginally suitable for irrigation. Whereas, 6.18% of slope, 1% of soil, and 21.09% of land use/cover were classified as not suitable for irrigation using surface application. It was also found much of the land is suitable for surface irrigation.

By weighing values of these constraint irrigation factor data sets by using AHP tool in Arc GIS, resulted from these analysis irrigation suitability maps was developed and potential irrigation land for irrigation was as 1.81%, 5.64% 86.83%, and 5.72% for S1, S2, S3, and N respectively. Based on the data from meteorological station, the irrigation water requirement was calculated using FAO-Penman-Monteith methods. By using Crop Wat version 8.0 model, the irrigation requirement of the selected crops was calculated and the result implies that irrigation water requirement was higher at driest months of the year.

The suitability of irrigation water was evaluated in terms of Soil, slope, LULC, road and river proximity. In conclusion Potential irrigable land was drawn by comparing the gross irrigation demand of identified irrigable land with respect to available monthly river flow.

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