Hydrospatial Analysis

Homepage: www.gathacognition.com/journal/gcj3
http://dx.doi.org/10.21523/gcj3

Original Research Paper

Site Suitability Analysis for Surface Irrigation using GIS, Remote Sensing, and Analytical Hierarchy Process (AHP) Integration in Wama Watershed, Western Ethiopia

Dawit Girma Burayu[1]*, Kitessa Merga Shiferaw[2]

1. College of Engineering and Technology, Wolkite University, P. O. Box 07, Wolkite, Guragie Zone, SNNPR, Ethiopia.
2. College of Engineering and Technology, Dilla University, Dilla, Ethiopia.

Abstract

The study integrates GIS, Remote Sensing and Analytical Hierarchy Process (AHP) to evaluate suitable sites for surface irrigation by taking eight parameters into account, including slope, elevation, distance to water source, land use, soil texture, soil type, soil depth, and soil drainage in Wama watershed. A numeric range was created by standardizing each parameter to a single measurement scale, with higher values denoting more suitable and lower values denoting less suitable one. The final site suitability map was prepared in GIS environment by using the weighted overlay method. Distance to streams (44%), slope (18%), elevation (13%), LULC (13%), and soil drainage (5%) scored highly in the pairwise comparison matrix. Additionally, they are the most crucial elements in evaluating eligible lands for surface irrigation, followed by soil depth (4%), soil type (3%), and soil texture (2%). The final suitability map, which will aid in supporting *rain-fed* agriculture by surface irrigation, was developed with four classifications highly suitable (16%), moderately suitable (49%), marginally suitable (34%), and not suitable (1%). Therefore, this study demonstrates a robust method of using GIS and remote sensing techniques, which is efficient and useful in mapping potential site suitability for surface irrigation and an important guideline for planners, and decision-makers to give the fast decision for irrigation management.

Article History

Received: 20 July 2022
Revised: 10 September 2022
Accepted: 10 September 2022

Keywords

AHP;
GIS;
Irrigation;
Remote Sensing;
Site Suitability.

Editor(s)

P. Hire

1 INTRODUCTION

Ethiopia is referred as the “African Water Tower” because of its terrain and weather (Teshome and Halefom, 2020). The country receives a considerable quantity of rainwater resource, approximately 980 BMC [Billion Meter Cube] annually (Hussien *et al.*, 2019). Agriculture is the backbone of economy with huge capacity of spreading irrigated agriculture in Ethiopia. However, irrigation infrastructures are still insufficient and contributing modestly to the expansion of agricultural sector. The country is primarily dependent on agriculture supported by rainfall alone (Shitu and Berhanu, 2020), which is extremely sensitive to rainfall variability and unpredictability, although few initiatives and legacies are being launched by the Ethiopian governments. The majority of Ethiopia’s population resides in the highlands, where 85% of the population is rural and depends on *rain-fed* agriculture (World Bank, 2006) with minimal inputs and output with little irrigation (Dawit *et al.*, 2020). Agriculture is the main engine of Ethiopia’s growth in addition to directly sustaining the livelihoods of the society. Drought susceptibility is an increasing issue as a result of severe climate change, rapid growth in population, shrinking land holding size, rising landlessness, land degradation, subsistence farming and *rain-fed* agriculture (Aybehon and Tiku, 2022). There are frequent crop failures due to dry spells and droughts led to food insecurity frequently turns into famine (Gonfa *et al.*, 2021).

* Author address for correspondence
College of Engineering and Technology, Wolkite University, P.O.Box 07, Wolkite, Gurагie Zone, SNNPR, Ethiopia.
Tel.: + 251 917736107
Emails: davegirma63@gmail.com (*D. Burayu* -Corresponding author); kitesamerga@gmail.com (*K. Shiferaw*)

https://doi.org/10.21523/gcj3.2022060104

This has a particular impact on the rural poor of Ethiopia and their means of subsistence. Despite having an abundance of water resources, the country has historically experienced terrible droughts (Girma *et al.*, 2020). As a result, the people of this great civilized country lived in poverty for many years.

Due to heavily reliance on *rain-fed* agriculture and the unpredictable nature of rainfall, alternative strategies for boosting agricultural productivity must be developed in Ethiopia and the irrigation development should be maximized (Wubalem, 2021). Ethiopia is currently working to establish effective water resource management strategies and to take advantage of the potential irrigation in its river basin (Kassie, 2020). One of Ethiopia's longest basins with the potential for surface water irrigation is the Upper Blue Nile River Basin (Teshome and Halefom, 2020; Dawit *et al.*, 2020). However, there is a need for clear and flexible irrigation management. The river basin features in the Wama watershed are vital to know the entire potential of the land resources and available surface water for irrigation (Burayu, 2022). Growing irrigation demand combined with shifting land use patterns, population growth, climate change and variability is a serious problem for surface water irrigation in the Wama watershed. Irrigation is one of the solutions to the food shortage in the region where *rain-fed* agriculture practiced (Wubalem, 2021; Gonfa *et al.*, 2021). It moves water from a source with plenty of water to fields with little water because of constructed structures. It can contribute to the reduction of destitution and the achievement of food self-sufficiency by giving farmers more income during the dry seasons (Kebede and Ademe, 2016).

In the Wama Watershed, *rain-fed* agriculture is the only practiced method for growing crops (Wubalem, 2021). Because of the region's high level of regional and temporal rainfall variability, food insecurity is a prevalent problem (Nigussie *et al.*, 2019). Uncertainty in rainfall distribution resulted in crop failure and droughts. As a result, in the face of even small setbacks, food insecurity can soon turn into famine, wreaking havoc on the existence of the poor rural community (Shitu and Berhanu, 2020). The most important strategy for transforming low-output *rain-fed* agriculture into the most effective and efficient irrigated agriculture is to use water to quadruple crop output during the arid season (Aybehon and Tiku, 2022; Negasa and Wakjira, 2021; Shitu and Berhanu, 2020). However, there hasn't been any study done on-site appropriateness evaluations for surface irrigation (Burayu, 2022). To sustain *rain-fed* agriculture through irrigation, which will help to reduce poverty in the watershed, site suitability assessment for surface irrigation is essential in this area (Nigussie *et al.*, 2019). A necessity for better land resource usage, which helps in the optimization and sustainability of these land resources' production, is proper site suitability appraisal of the available land resources in the irrigation command area (Negasa and Wakjira, 2021). Access to irrigation influences both changes in land use and the adoption of intensive farming techniques. On the other hand, irrigation is not always appropriate for all regions (Teshome and Halefom, 2020). The AHP method is commonly employed (Saaty, 1980) to account a number of factors including land use, topography, and various soil properties (physical and chemical) for classifying surface irrigation sites according to their suitability as one of the crucial steps in planning for many objectives. The main goal of this study is to detect the suitable lands for surface irrigation in the Wama watershed using the AHP, RS and GIS techniques. This analysis will help in selecting appropriate sites for surface irrigation and planning and managing the land use.

2 MATERIALS

2.1 Study Area

Didessa sub-basin of Wama (Figure 1) is one of the most significant watersheds according to the yearly contribution to runoff. Geographically, the sub-basin is located between 08º10′ and 9º10′ N and 36º 05′ and 36º 05′E in Western part of Ethiopia (Burayu, 2022). The elevation in the basin ranges between 1174m and 3083m. The catchment area is of about 3344.4 km^2 with mean annual rainfall of 1934.64 mm and the maxima in Didessa sub-watershed (Burayu, 2022). The mean annual runoff is about 448mm. The humid tropical climate observed in the watershed with high yearly rainfall during rainy periods. The temperature ranges from 21-31ºC and 10-15 ºC. Wama is dominated by the Jimma Volcanic, the Wellega Basalt in the middle, and the undifferentiated lower complex, Wellega Basalt, and Adigrat Sandstone in the lower parts.

2.2 Data

Site suitability study for surface irrigation requires a sufficient amount of high-quality data. As a result, relevant data about the topography, accessibility, soils, and water source was acquired from a variety of sources. These parameters were compiled by the FAO and USGA. Depending on the availability of data, the regional circumstances in the watershed, the agricultural background, and the appraisal of the literature, eight input factors namely slope, elevation, soil types, soil textures, soil drainage, soil depth, and LULC were selected for investigation. The information about physical characteristics of soil including soil depth, soil drainage, soil texture, and soil type were procured from the Food and Agriculture Organization (FAO, 1985). The suitability of land for agricultural use will depend on several factors, including the topographic features of the area. While elevation can determine the local climate, a slope can control how quickly erosion and deposition occur. The slope and elevation are topographic characteristics, which were retrieved from the DEM. The distance from streams was calculated using Euclidian distance. The map showing LULC of the region was created using and Landsat ETM+ data and supervised classification technique in GIS software.

3 METHODOLOGY

In this study, suitable sites for surface irrigation were detected based on datasets of eight land surface characteristics viz. slope, soil types, soil textures, soil drainage, soil depth, LULC, elevation, and distance from streams. The data of input parameters for a GIS-based site suitability were transformed into the same pixel size of 30m x 30m with an equivalent projection. The significance of each sub-criteria was used to reclassify and standardize the rasterized characteristics. The weight assigned to each criterion was then determined using a pairwise comparison matrix. The weighted overlay algorithms in ArcGIS were used to add the weighted criteria and provide a site appropriateness index. After all, natural break method in the ArcGIS was used to reclassify the site suitability indexed map into four suitability classes (Figure 2).

3.1 Weight Assessment and Normalization

A pairwise comparison matrix was created for each map based on the weighting of each criterion (Saaty 1980) using AHP based Multi-Criteria Decision Making (MCDM) technique along with the rates for classes in input layers namely slope, elevation, soil types, soil textures, soil drainage, soil depth and LULC. The matrix was used to compare the criteria based on Saaty's scale of 1 to 9 (Table 1). The relative scores of their classes were taken into account while calculating the cumulative weightages of the criteria. Weightages calculated using AHP technique (Saaty, 1980) and normalized considering the relative importance of criteria and classes to determine the potential suitable sites for surface irrigation. The Consistency Ratio (CR) was calculated in accordance to evaluate the normalized weights of distinct thematic layers and their specific classes.

Table 1. Saaty's scale of relative importance

Relative importance	Definition
1	Equal importance
2	Weak or slight
3	Moderate importance
4	Moderate plus
5	Strong importance
6	Strong plus
7	Very strong
8	Very, very strong
9	Extremely importance

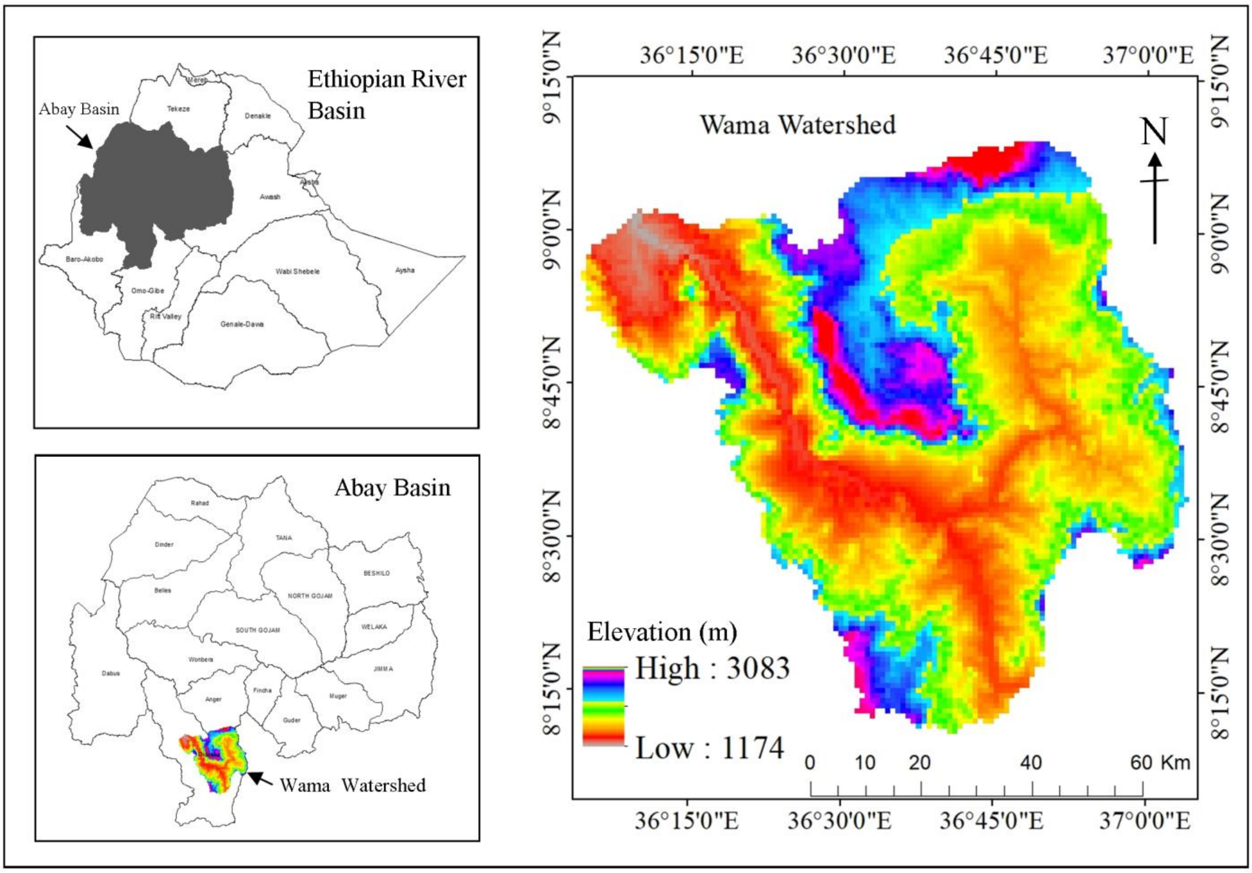

Figure 1. Study Area: Wama watershed in Ethiopian river basin

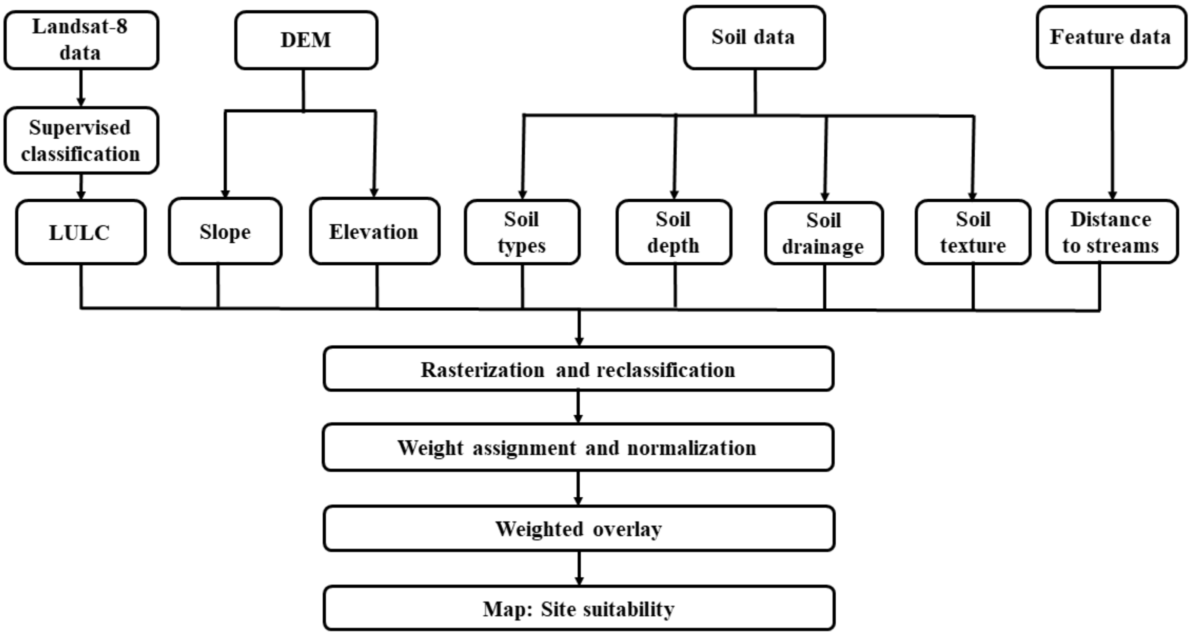

Figure 2. Methodology

3.2 Overlay Analysis

After allocating rates for classes within a layer and weights for thematic layers, the final map (Figure 11) was produced by superimposing all thematic maps (Burayu, 2022; Neissi *et al*., 2019; Girma *et al*., 2020) with the help spatial analysis tool in GIS software.

4 RESULTS AND DISCUSSION

4.1 Thematic layers

One of the crucial elements in a site suitability analysis for surface irrigation is the preparation of thematic layers. For this study, a single database for criteria maps was created. The characteristics were transformed into a projection system and equal resolution.

4.1.1 Slope

The slope, which is typically given in percent, is the inclination or gradient of a surface. Due to its impact on runoff, drainage, erosion, and crop selection, the slope is crucial for the creation and maintenance of soil. The gradient has a significant impact on duration of irrigation cycle, crop adaptation, erosion prevention and irrigation technique. As the gradient rises, the risk of erosion increases in surface irrigation. So, the water management is useful to reduce the length of irrigation runs and crop options. The irrigation management become more significant in steep sloped area. In general, steep gradients lead to reduce productivity and greater production costs. Therefore, slopes were derived using digital elevation model (DEM) with 30m resolution from the Shuttle Radar Topography Mission (SRTM) and used for this site suitability analysis for surface irrigation. The raster layer was classified into four groups with corresponding suitability ratings of 1 to 4: (4 = Highly suitable, 3 = Moderately suitable, 2 = Marginally suitable, and 1 = Unsuitable). The result obtained after reclassifying the slope map was that 15% (448.1km^2) of the watershed was less than 2%, 39 % (1289km^2) of the watershed, 2-5%, 23% (756.3km^2), 5-8% and 24% (811.5km^2) of the watershed is higher than 8% slope. This shows that 76% (2532.9km^2) of the study area was revealed to be appropriate for surface irrigation.

4.1.2 Elevation

The elevation was rescaled and classified into four classes: extremely suitable class (4) for elevation ranges from 1170m to 1500m, moderately suitable class (3) for elevation ranges from 1500m to 1750m, marginally suitable class (2) for elevation ranges from 1750m to 2060m, and unsuitable class (1) for elevation ranges from 2060m to 3080m. The highly suitable land class is covered by approximately 35% (1174km^2), the moderately suitable land class (3) is covered by approximately 31% (1032km^2), and the marginally suitable land class (2) is covered by approximately 21% (694km^2), and the unsuitable land class (1) is covered by approximately 13% (174.2km^2).

4.1.3 Soil Depth

Based on the required soil depth for the majority of common crops to have the option of surface irrigation, the soil depth was classified into acceptable classes. Rating parameters for soil depth were supplied and weighted to determine if the study area was suitable for surface (gravity) irrigation. Based on the suitability score assigned for each soil depth, a map showing the soil depth suitability after being converted to raster and divided into four categories with accompanying suitability scores of 1 to 4. According to the suitability map, 32% of the area (1078.5km^2) is classified as highly appropriate, compared to 21% (691.1km^2) for moderate suitability and 47% (1574.7km^2) for marginal suitability.

4.1.4 Soil Drainage

Normal plant development is possible due to soil drainage. Elevation of the soil drainage is important when choosing sites for surface irrigation, especially with diverse highland crops. Ample soil drainage is crucial to ensuring continued production and enabling productivity in agricultural operations. The efficient removal of the additional water and salts that irrigation contributes requires consideration of new irrigation facilities. A area with efficency of drainage may be classified as well-drained, moderately drained, imperfectly drained, severely drained, or extremely poorly drained depending on the techniques used to measure a permeability of soils. Therefore, the soil drainage properties were classified into well drained, moderately drained, imperfectly drained, and poorly drained. In our case, we give suitability class and score for each of the soil drainage classes as 4 (highly suitable), 3 (moderately suitable), 2 (marginally suitable), and 1 (unsuitable). We convert soil drainage map to raster and reclassify it to know area coverage of each soil drainage classes. From drainage suitability map, 75.4% (2522km^2) is classified as 4 (highly suitable), 7.5 % (250km^2) is 3 (moderately suitable), 16% (535.6km^2) is 2 (marginally) and 1.1% (36.4km^2) is unsuitable (Figure 6).

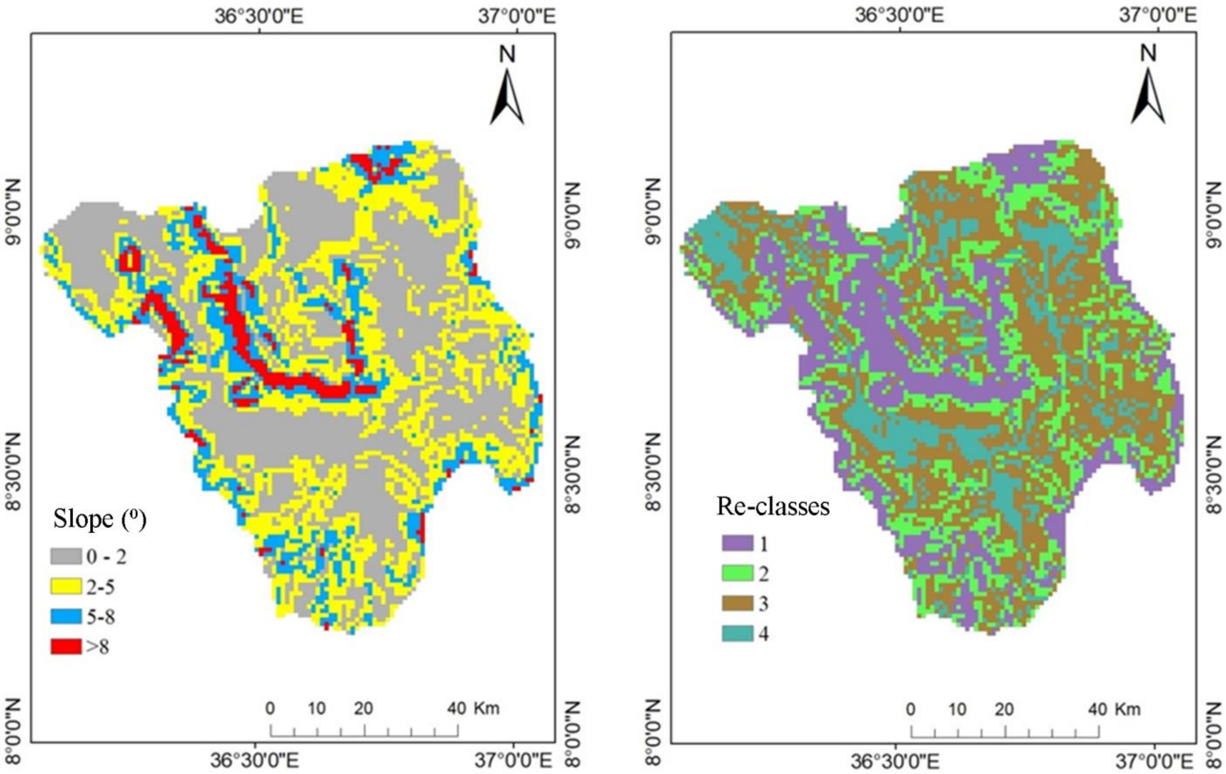

Figure 3. Slope

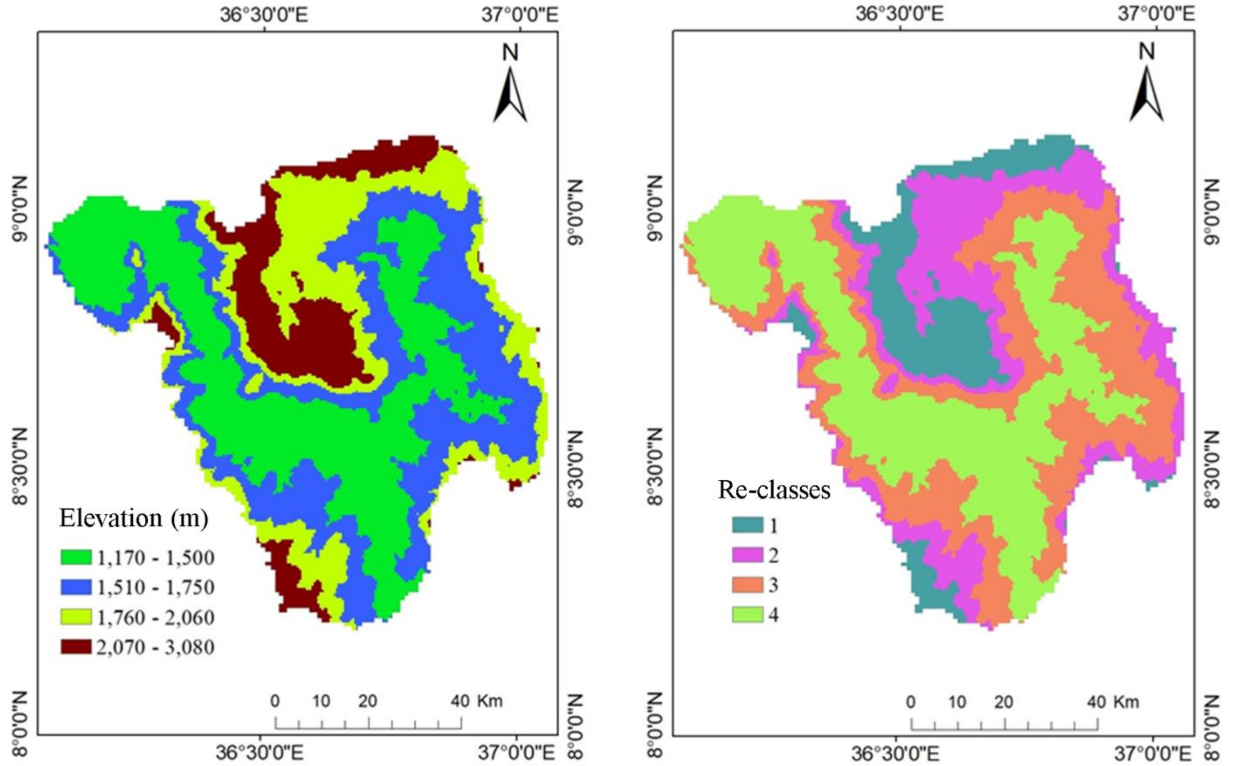

Figure 4. Elevation

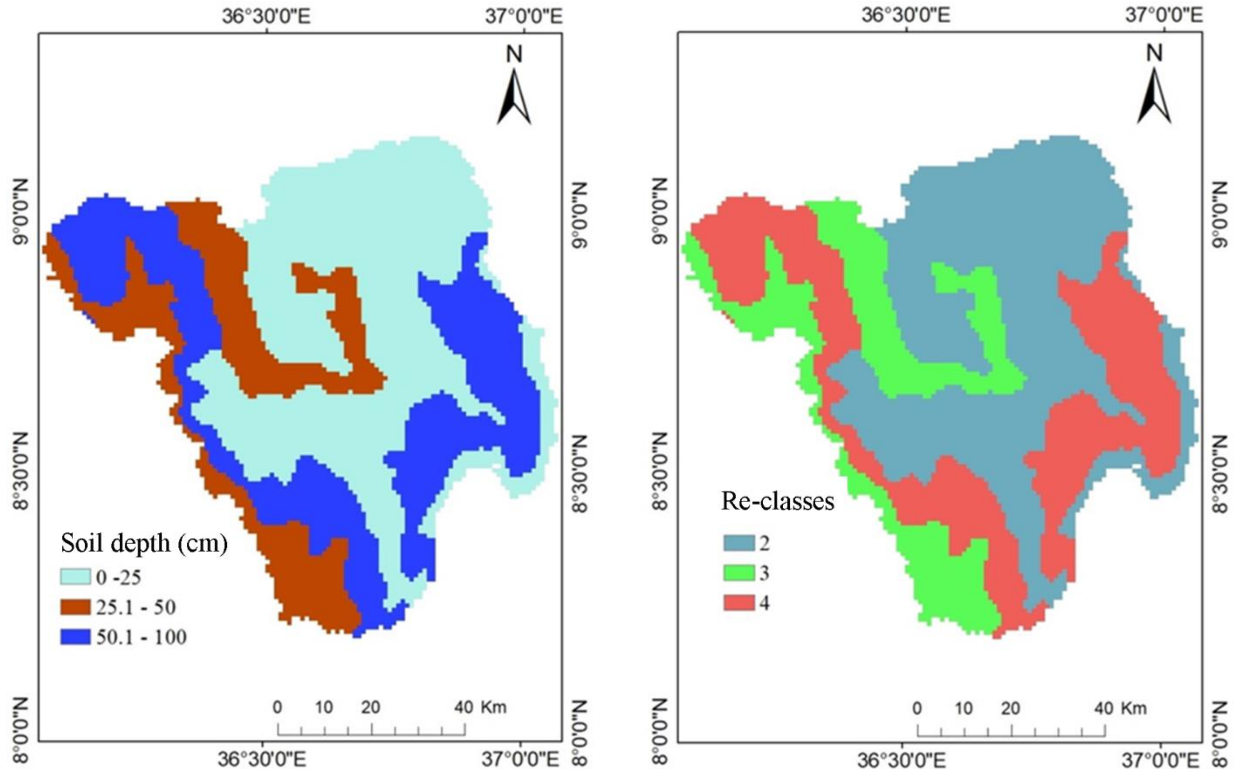

Figure 5. Soil depth

4.1.5 Soil Type

There are four types of soils observed in the Wama watershed: Humic Nitisols, Humic Alisols, Eutric Vertisols, and Lithic Leptosols. Most of the Wama watershed is covered by Humic Nitisols. The soil type mentioned above are standardized for land suitability assessment as Humic Nitisols are 4 (highly suitable), Eutric Vertisols are 3 (moderately suitable), Humic Alisols are 2 (marginally suitable) and lithic leptosols are 1 (unsuitable). We convert the soil type map to raster and reclassify it to know the area coverage of each soil type class. From soil type suitability map 77.24% (2583km^2) (highly suitable), 17.93% (599.72km^2) (moderately suitable), 4.79% (160.33km^2) (marginally suitable) and the left 0.0004% (1.3km^2) (unsuitable) (Figure 7).

4.1.6 Soil Texture

According to the FAO (1985) guidelines for site suitability classification, soil textural classes like clay, clay loam, and loam soil were classified as highly suitable (4), silt and silty loam were classified as moderately suitable (3), and sandy loam soil texture was classified as marginally suitable (2) for surface irrigation with the restriction factor of high infiltration rate. The classes of soil texture in the study region were determined by the percentage of the soil hydrological group, which includes loam, clay loam, and clay. The soil texture classes and their respective suitability levels are highly suitable (4), clay soil is classified as moderately suitable (3) and sandy loam is as marginally suitable (2). From soil texture suitability map 82% (2743km^2) (highly suitable), 17.93% (599.72km^2) (moderately suitable), and 0.0004% (1.3km^2) (marginally suitable) (Figure 8).

4.1.7 Land Use Land Cover

Another element used to assess the suitability of the area for irrigation is land use land cover (LULC). The Landsat 8 image was used to create the LULC map. It was categorized as very suitable (4), moderately suitable (3), marginally suitable (2), and not suitable (1). While grassland is rated as somewhat suitable (3), cropland was categorized as highly suitable (4). Due to the initial land investment required, woodland, shrub, and bush were rated as only slightly acceptable (2). The classification of the forest, barren land, water body, and settlements is unsuitable (1) (Figure 9). LULC categorized under highly suitable class covers 47% (1582.4km^2), moderately suitable 15% (500km^2), marginally suitable class 15% (500km^2) and 23% (775km^2) is under unsuitable class.

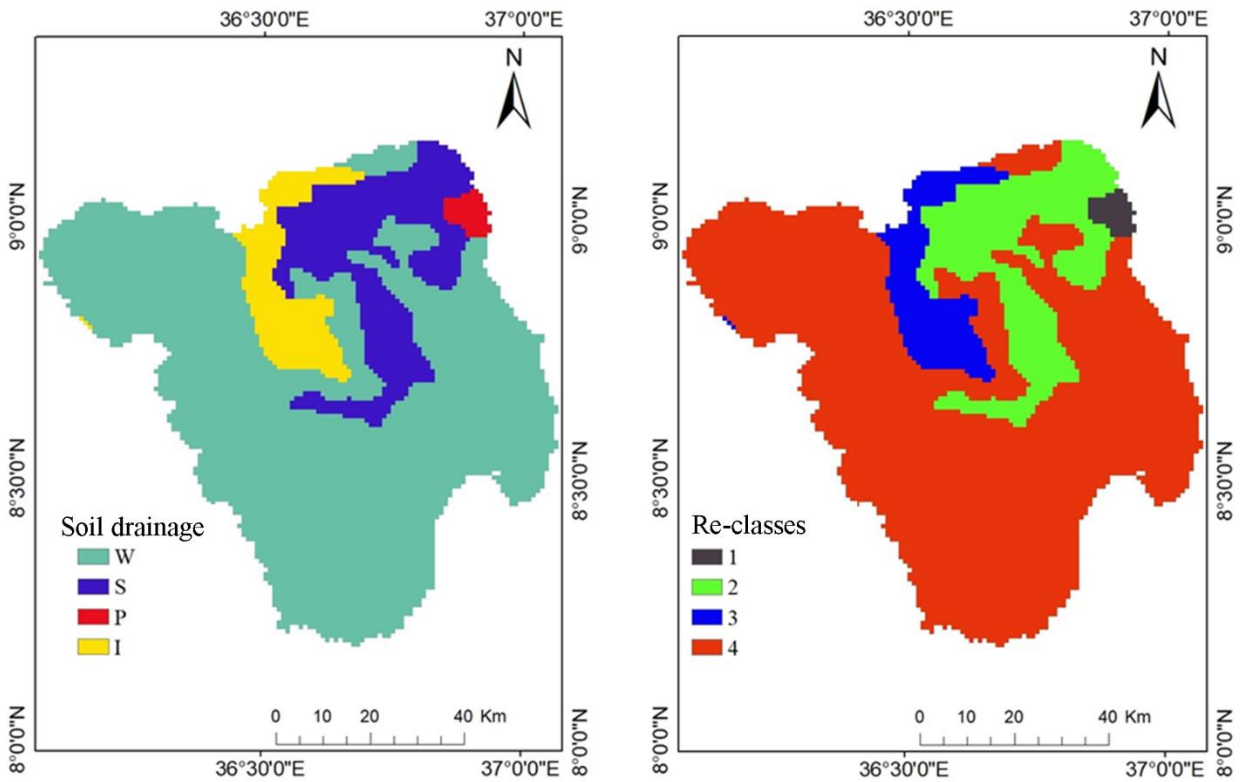

Figure 6. Soil drainage

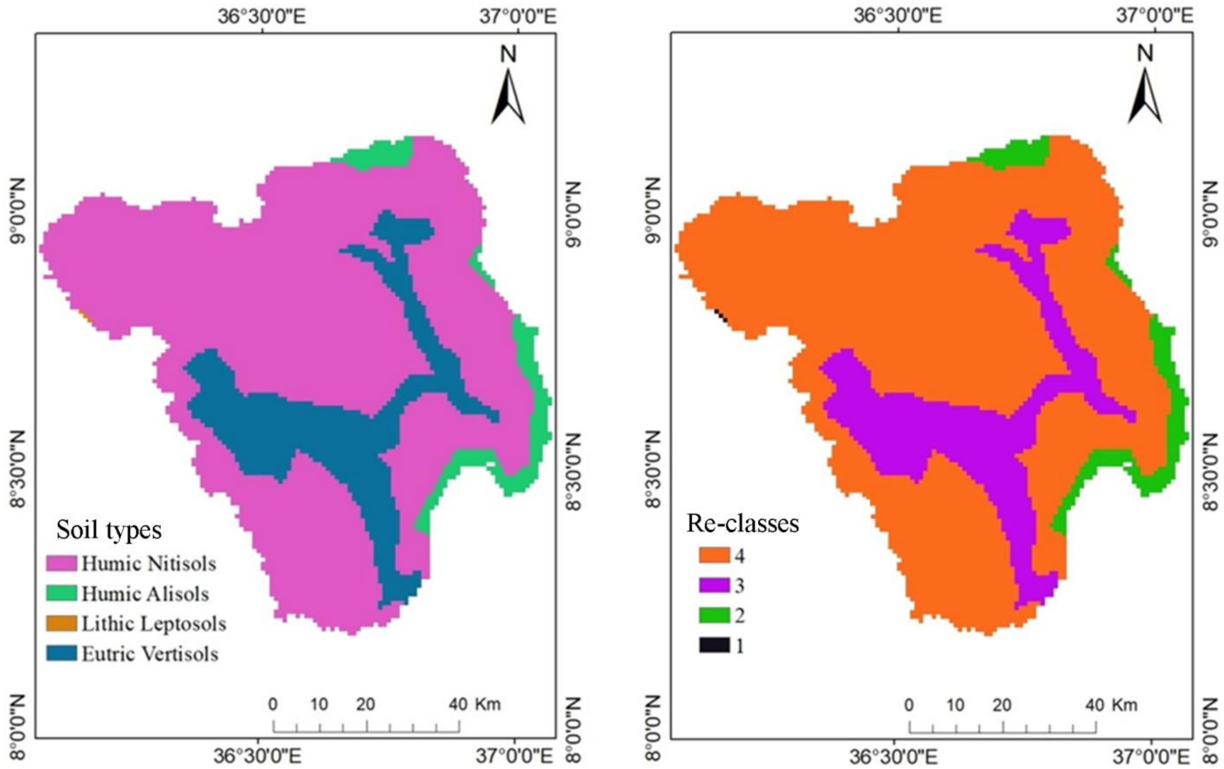

Figure 7. Soil types

4.1.8 Distance to Streams

One of the most crucial aspects of site suitability evaluations for surface irrigation is the assessment and determination of the distance to the water source. Euclidean distance in ArcGIS was used to calculate the distance from the water source, which was then categorized into four categories: 0-1.5km (very suitable, 4), 1.5-3km (moderately suitable, 3), 3-5km (marginally suitable, 2), and >5km (unsuitable, 1) (Figure 10). Distance to streams categorized under highly suitable class covers 30.7% (1026.6km^2), moderately suitable 24.6% (823.46km^2), marginally suitable class 19.5% (652km^2) and 25.2% (842.25km^2) is under unsuitable class.

4.2 Weighting and Combining

The parameters used to generate the rasterized and categorized surface irrigation site suitability maps have been weighted. Saaty's approaches were used in this study for each map and a pairwise comparison was prepared using 9-point significance scale in AHP. AHP is a multi-criteria decision-making strategy that offers a logical way of assessing and taking into consideration the consequences of numerous issues by connecting various level-dependent, qualitative and quantitative information. It was a method for accurately estimating the pairwise comparison-based qualified significance of a set of performances. Prioritizing the relative importance of each element that was qualified for a particular factor was done using weighting procedures. The weighted overlay element is more significant concerning other factors the higher the burden. A consistency ratio of 0.1 was considered acceptable. The calculated consistency ratio of 0.099 was accepted to demonstrate a certain matched weight (Saaty, 1978). The slope, elevation, soil texture, soil drainage, soil depth, LULC, and soil types all receive substantial weights in the pairwise evaluation, but the distance to the stream is assigned the largest weight (Saaty, 2004). The effectiveness of careful effect on the origin of contribution requirements is explained by numerical algorithms, and this influence is mutually influenced by various mathematical or logical methods of assessing disagreement. In this method, the influence value range of 1 to 9 was assigned to each aspect, and relationship outcomes were replicated by professionals. Using the weighted linear combination technique, each map layer was a critical step in the AHP. On a scale from 1 to 1/9, map was stacked in GIS spatial assessment for an appropriate site zone imitation (Burayu, 2022). The pairwise comparison matrix was prepared to estimate the relative importance of the elements (Saaty, 1980). The relationship between a value and intensity of less importance was as follows: 1= equal importance, 1/3 = moderate, 1/5 = strong, 1/7 = very strong, 1/9= extremely at the contrary, high significant variables were rated between 1 and 9. Each map layer was piled in a final GIS spatial assessment for suitable site zone imitation using the weighted linear combination technique.

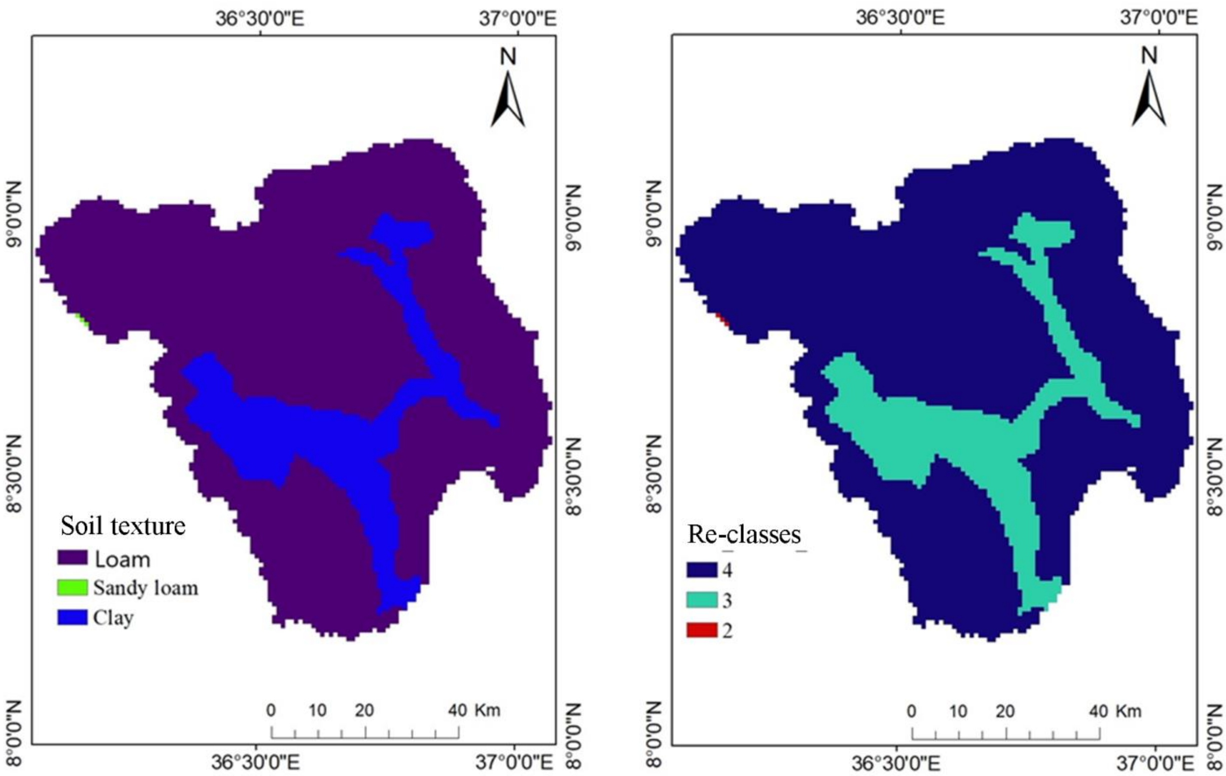

Figure 8. Soil texture

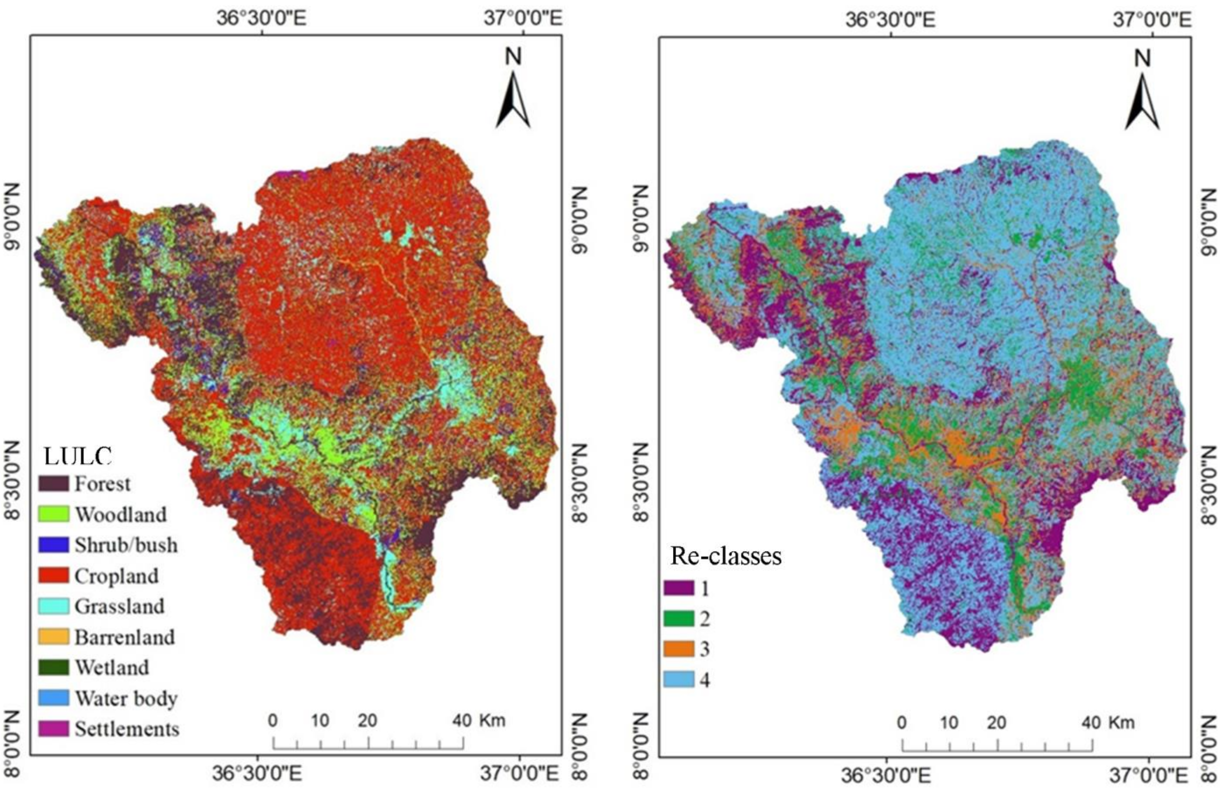

Figure 9. LULC

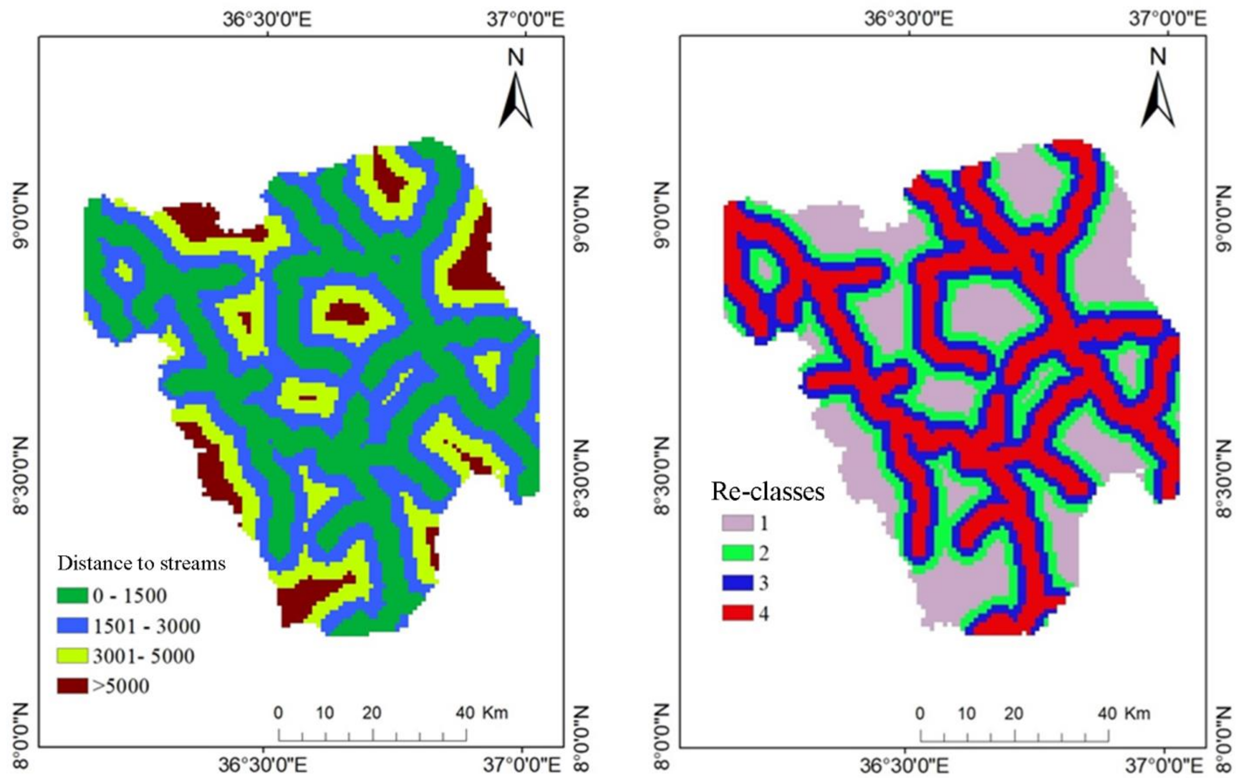

Figure 10. Distance to streams

Table 2. Pairwise comparison matrix

Criteria	Distance to streams	Slope	Elevation	LULC	Soil drainage	Soil depth	Soil type	Soil texture
Distance to streams	1	5	7	9	9	9	9	9
Slope	0.2	1	3	2	5	7	7	7
Elevation	0.14	0.33	1	2	7	5	5	5
LULC	0.11	0.5	0.5	1	5	7	7	7
Soil drainage	0.11	0.2	0.14	0.2	1	1	2	5
Soil depth	0.11	0.14	0.2	0.14	1	1	2	2
Soil type	0.11	0.14	0.2	0.14	0.5	0.5	1	2
Soil texture	0.11	0.14	0.2	0.14	0.2	0.5	0.5	1
Sum	1.9	7.46	12.24	14.63	28.7	31	33.5	38

Table 3. Normalized pairwise matrix

Criteria	Distance to streams	Slope	Elevation	LULC	Soil drainage	Soil depth	Soil type	Soil texture
Distance to streams	0.5	0.67	0.57	0.61	0.31	0.29	0.27	0.24
Slope	0.1	0.13	0.25	0.13	0.17	0.23	0.21	0.18
Elevation	0.1	0.04	0.08	0.13	0.24	0.16	0.15	0.13
LULC	0.1	0.07	0.04	0.07	0.17	0.23	0.21	0.18
Soil drainage	0.1	0.03	0.01	0.01	0.03	0.03	0.06	0.13
Soil depth	0.1	0.02	0.02	0.01	0.03	0.03	0.06	0.05
Soil type	0.1	0.02	0.02	0.01	0.02	0.02	0.03	0.05
Soil texture	0.1	0.02	0.02	0.01	0.01	0.02	0.01	0.03
Sum	1	1	1	1	1	1	1	1

Table 4. Relative weights

Criteria	Distance to streams	Slope	Elevation	LULC	Soil drainage	Soil depth	Soil type	Soil texture	Weight	W (%)
Distance to streams	0.5	0.67	0.57	0.61	0.31	0.29	0.27	0.24	0.437	43.7
Slope	0.1	0.13	0.25	0.13	0.17	0.23	0.21	0.18	0.177	17.7
Elevation	0.1	0.04	0.08	0.13	0.24	0.16	0.15	0.13	0.128	12.8
LULC	0.1	0.07	0.04	0.07	0.17	0.23	0.21	0.18	0.128	12.8
Soil drainage	0.1	0.03	0.01	0.01	0.03	0.03	0.06	0.13	0.046	4.61
Soil depth	0.1	0.02	0.02	0.01	0.03	0.03	0.06	0.05	0.035	3.54
Soil type	0.1	0.02	0.02	0.01	0.02	0.02	0.03	0.05	0.027	2.75
Soil texture	0.1	0.02	0.02	0.01	0.01	0.02	0.01	0.03	0.021	2.1
Sum	1	1	1	1	1	1	1	1	1	100

Table 5. Rating and weightages

Criteria	Classes	Suitability classes	Rating	Weightage (%)
Distance to streams	0 - 1500	Highly suitable	4	43.7
	1501 - 3000	Moderately suitable	3	
	3001- 5000	Marginally suitable	2	
	>5000	Not suitable	1	
Slope	0 - 2	Highly suitable	4	17.7
	2 - 5	Moderately suitable	3	
	5 - 8	Marginally suitable	2	
	>8	Not suitable	1	
Elevation	1170 - 1500	Highly suitable	4	12.8
	1500 - 1750	Moderately suitable	3	
	1750 - 2060	Marginally suitable	2	
	2060 - 3080	Not suitable	1	
Soil texture	Sandy loam	Marginally suitable	2	12.8
	Clay	Moderately suitable	3	
	Loam	Highly suitable	4	
Soil drainage	Well drained	Highly suitable	4	4.61
	Moderately well drained	Moderately suitable	3	
	Imperfectly poor drained	Marginally suitable	2	
	Poorly drained	Not suitable	1	
Soil depth	0-25	Marginally suitable	2	3.54
	25.1 - 50	Moderately suitable	3	
	50.1 - 100	Highly suitable	4	
LULC	Forest/water body/settlements	Not suitable	1	2.75
	Shrub/bush/grassland	Marginally suitable	2	
	Woodland/barrenland/wetland	Moderate suitable	3	
	Cropland	Highly suitable	4	
Soil type	Lithic leptosols	Not suitable	1	2.1
	Humic alisols	Marginally suitable	2	
	Eutric vertisols	Moderate suitable	3	
	Humic nitisols	Highly suitable	4	

4.3 Suitable Site Mapping for Surface Irrigation

Analyzing the suitability of a site is crucial to identifying the best locations for surface irrigation in light of numerous considerations. The goal of the current study was to identify the likely viable farmlands for surface irrigation within the Wama watershed. In this work, the association between soil physical characteristics, topography (slope and elevation), and LULC determinants on the appropriateness of locations for surface irrigation was assessed using an AHP method with GIS. An 8x8 pairwise comparison matrix was used to establish the relationship between governing criteria and site suitability (Table 1). Eight governing characteristics, including topographic factors (slope and elevation), land use, physical factors (soil texture, drainage, type, and depth), and distance to water source were taken into account for this study. Eight important factors were compared one to at least one in the pairwise comparison matrix, and the Saaty's scale was used to score the results (Saaty, 1980). The normalized weights for each parameter were calculated using the matrix's average row sum (Table 3). An overview of the relative significance of each parameter is given in Table 4. The distance from streams (44%), slope (18%), elevation (13%), LULC (13%), and soil drainage (5%) are the most important parameters in evaluating ideal sites for surface irrigation (Table 4). Soil depth (4%), soil type (3%), and soil texture (3%) are the next three factors (2%). Weighted overlay analysis (WOA) is carried out in an ArcGIS environment following the generation of weights for each raster layer using AHP. During suitability analysis, the weighted overlay is created by intersecting standardized and variably weighted layers. The weights quantify the relative weights of the taken into account appropriateness criteria. The suitability scores assigned for the sub-criteria inside each criteria layer were multiplied by the weights assigned for each criterion to create the final suitability map using the WOA approach.

$$S = \sum_{i=1}^{n} WiXi$$

where, S is the overall suitability score, Wi is the weight allocated to the layer of suitability criterion that was chosen, Xi is the sub-criteria score that was assigned to layer i of suitability criteria, and n is the total number of suitability criteria.

$$S = 0.437 \times [\text{Distance to stream}] + 0.177 \times [\text{Slope}] + 0.128 \times [\text{Elevation}] + 0.128 \times [\text{LULC}] + 0.0461 \times [\text{Soil drainage}] + 0.0354 \times [\text{Soil depth}] + 0.0275 \times [\text{Soil types}] + 0.021 \times [\text{Soil texture}]$$

A combined suitability map was produced by the weighted overlay analysis that was done utilizing the factors that were taken into consideration and their relative weights. The final map of suitability displayed the geographic distribution of the land types that were appropriate for surface irrigation (Figure 11). According to the surface irrigation suitability map, 16% (530km^2) of the area is inappropriate, 49% (1648km^2) is moderately acceptable, 34% (1128km^2) is marginally suitable, and 16% (530 km^2) is severely unsuitable. From the total study, area 1% (39km^2) of the study area is covered by a not suitable area. According to the study, this is frequently caused by being far from the source of water, a steep gradient, excessive drainage, minimal soil depth, high elevation, settlements, forests, water bodies, leptosols, and poor drainage which is consistent with the work of (Aybehon and Tiku, 2022; Hussien *et al.*, 2019). The 34% (1128km^2) area was covered by a marginally suitable class (2). Because of its uneven soil drainage, moderate elevation, location just on the edge of a water body, sandy loam soil type, relatively shallow soil depth, and bush land, this region is consistent with the work of (Aybehon and Tiku, 2022; Wubalem, 2021; Hussien *et al.*, 2019). Approximately, 49% (1648 km^2) of the overall research region is covered by a class that is just somewhat appropriate (3). Due to the existence of grassland, nitisols, somewhat deep soil, and soil mass that is moderately drained, which is consistent with the study of (Hussien *et al.*, 2019; Negasa and Wakjira, 2021; Wubalem, 2021). Due to the existence of well-draining soil, nitisols type, low raised land, closest to water sources, clay soil texture, and already cultivated lands, the highly suitable class (4) is covered by roughly 16% (530 km^2), which is consistent with the work of (Aybehon and Tiku, 2022; Negasa and Wakjira, 2021; Hussien *et al.*, 2019). The overall findings demonstrated that the feasibility of land for surface irrigation within the study region was significantly influenced by physical characteristics including slope, soil depth, soil drainage, soil texture, soil type and altitude.

5 CONCLUSION

Using the integration of GIS, remote sensing, and the AHP approach, a final map of the site suitability for surface irrigation was prepared in the this study by assessing eight features. In the normalized pairwise comparison matrix, distance from a water source (44 %), slope (18 %), elevation (13 %), LULC (13 %), and soil drainage (5 %) received high ratings. They are also the most important factors in determining whether a piece of land is eligible for surface irrigation, ahead of factors like soil depth (4 %), soil type (3 %), and soil texture (2 %). The final suitable map was constructed with four classifications: extremely suitable (4), fairly suitable (3), marginally suitable (2), and not suitable (1) after a load of each parameter was chosen. This map will aid in surface irrigation ability to support *rain-fed* agriculture. According to the results, extremely suitable, moderately suitable, marginally suitable and not suitable land uses account for 16%, 49%, 34%, and 1% area of region, respectively. This study demonstrates how GIS may be used at different scales and is an effective tool for emphasizing the suitability of land for agriculture and assessing cross-tabulations between classes of thematic maps. The map created using this platform might therefore be used as a rough guide when choosing appropriate sites for surface irrigation in the area.

This investigation showed the spatial distribution of suitable and unsuitable lands for surface irrigation, the relevant body may also be at the Zonal/Woreda level and should measure to apply surface irrigation is highly appropriate regions (4) and moderately suitable regions (3). The land suitability for surface irrigation is the sole focus of this study. It is recommended that future studies take into account the water supply, the chemical composition of the soil, sociological conditions and economic variables for the region.

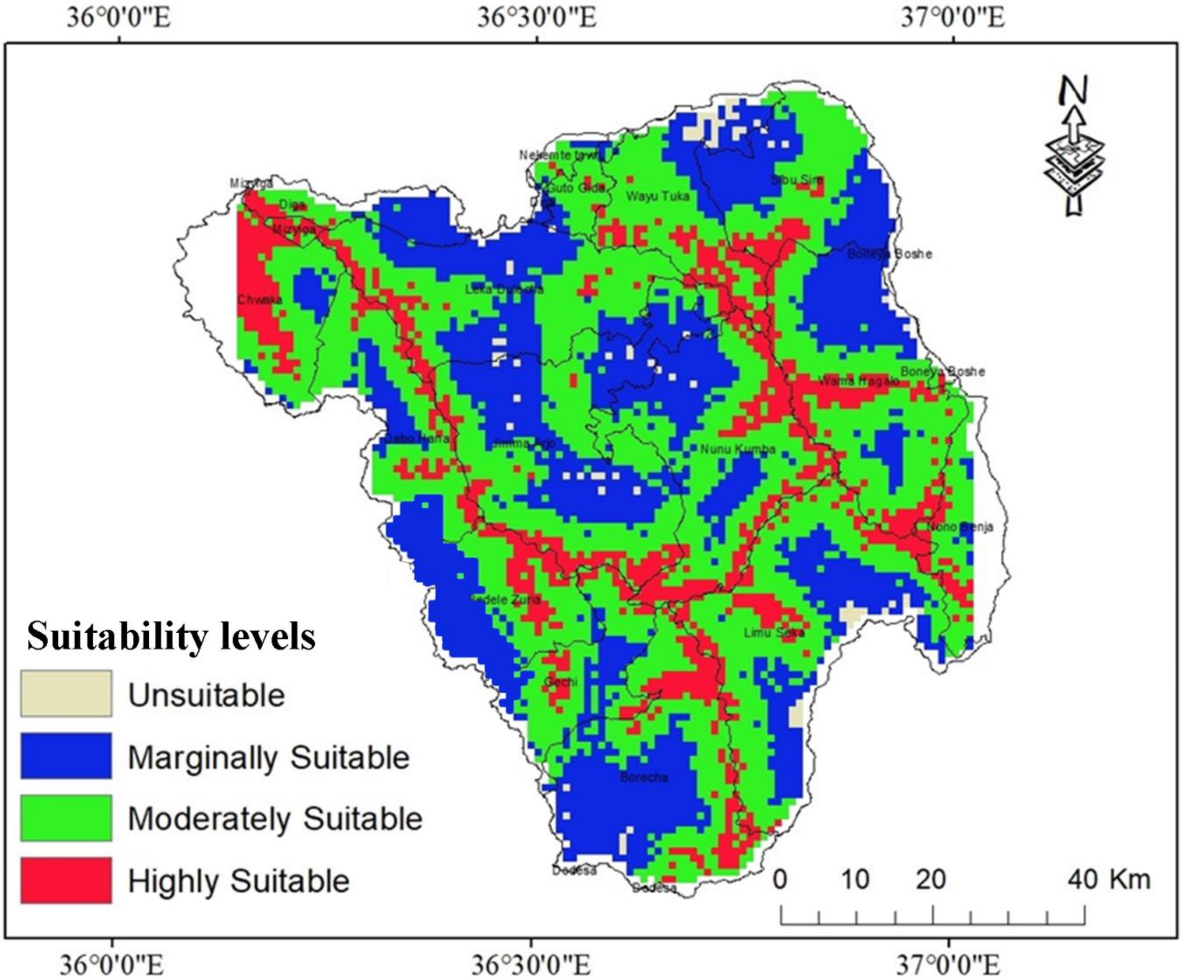

Figure 11. Site suitability for surface irrigation

CONFLICT OF INTEREST

Regarding the research, writing, and publication of this paper, the authors reported that they had no potential conflicts of interest.

ACKNOWLEDGEMENTS

The authors are highly indebted to Wolkite University and Dilla Universty for providing the required resources and assistance throughout the investigation.

ABBREVIATIONS

AHP: Analytical Hierarchy Process; **DEM**: Digital Elevation Model; **FAO**: Food and Agriculture Organization; **GIS**: Geographical Information System; **LULC**: Land Use Land Cover; **RS**: Remote Sensing; **SRTM**: Shuttle Radar Topographic Mission; **WOA**: Weighted Overlay Analysis.

REFERENCES

Aybehon, E. Y. and Tiku, A. A., 2022. Land suitability evaluation for surface irrigation using ARC GIS and AHP techniques in Bedessa, Ethiopia. *1st International Online Conference on Agriculture - Advances in Agricultural Science and Technology session Agricultural Water Management*, 1-15.

Burayu, D. G., 2022a. Estimation of Soil Loss Rate Using RUSLE Model Integrated with GIS and Remote Sensing Techniques: The Case of Wama Watershed, Western Wama Watershed, Western. *International Journal of Scientific Research and Innovative Studies (IJSRIS Journal)*, 1(1), 52-65. DOI: https://doi.org/10.5281/zenodo.6877849

Burayu, D. G., 2022b. Identification of Groundwater Potential Zones Using AHP, GIS and RS Integration: A Case Study of Didessa Sub-Basin, Western Ethiopia. *Remote Sensing of Land*, 6(1) 1-15. DOI: https://doi.org/10.21523/gcj1.2022060101

Dawit, M., Dinka, M. O., Leta, O.T. and Muluneh, F. B., 2020a. Impact of Climate Change on Land Suitability for the Optimization of the Irrigation System in the Anger River Basin, Ethiopia. *Climate*, 8, 97. DOI: https://doi.org/10.3390/cli8090097

Dawit, M., Olika, B. D., Muluneh, F. B., Leta, O. T. and Dinka, M. O., 2020b. Assessment of Surface Irrigation Potential of the Dhidhessa River Basin, Ethiopia. *Hydrology*, 7(3), 68. DOI: https://doi.org/10.3390/hydrology7030068

FAO [Food and Agriculture Organization], 1985. Guideline for Land Evaluation for Irrigated Agriculture. Soils Bulletin. *FAO, Rome.*, 55.

Girma, R., Gebre, E. and Tadesse, T., 2020. Land Suitability evaluation for surface irrigation using spatial information technology in Omo-Gibe river basin, Southern Ethiopia. *Irrigation and Drainage Systems Engineering*, 9(2), 1-10. DOI: https://doi.org/10.37421/idse.2020.9.245

Gonfa, B.G., Hatiye, S. D. and Finssa, M. M., 2021. Land suitability and surface water resources potential for irrigation in Becho Plain, upper Awash basin, Ethiopia. *Irrigation and Drainage*, 70(4), 936-957. DOI: https://doi.org/10.1002/ird.2575

Hussien, H., Woldu, G. and Birhanu, S., 2019. A GIS-Based multi-criteria land suitability analysis for surface irrigation along the Erer Watershed, Eastern Hararghe Zone, Ethiopia. *East African Journal of Sciences*, 13(2), 169-184.

Kassie, A. E., 2020. Challenges and opportunities of irrigation practices in Ethiopia: A Review. *Journal of Engineering Research and Reports*, 9(3), 1-12. DOI: https://doi.org/10.9734/jerr/2019/v9i317016

Kebede, T. and Ademe, Y., 2016. Evaluating land suitability for irrigation purpose in Abaya district, Borena zone, Ethiopia. *African Journal of Agricultural Research,* 11(46), 4754-4761. DOI: https://doi.org/10.5897/AJAR2016.11438

Negasa, G. and Wakjira, G., 2021. Assessment of irrigation land suitability for surface irrigation in Birbir River watershed using geographic information system technique in Oromia Region, Ethiopia. *Software Engineering*, 9(2) 45-52. DOI: https://doi.org/10.11648/j.se.20210902.12

Neissi, L., Albaji, M. and Nasab, S. B., 2019. Site selection of different irrigation systems using an analytical hierarchy process integrated with GIS in a Semi-Arid Region. *Water Resources Management*, 33, 4955-4967. DOI: https://doi.org/10.1007/s11269-019-02434-1

Nigussie, G., Moges, M. A., Moges, M. M., and Steenhuis, T. S., 2019. Assessment of Suitable land for surface irrigation in Ungauged catchments: Blue Nile Basin, Ethiopia. *Water*, 1-17. DOI: https://doi.org/10.3390/w11071465

Saaty, T. L., 1980. The analytic hierarchy process. *McGraw-Hill, New York*, 5.

Saaty, T. L., 2004. Decision making - the analytic hierarchy and net work processes (AHP/ANP). *Journal of Systems Science and Systems Engineering*, 13, 1-35. DOI: https://doi.org/10.1007/s11518-006-0151-5

Saaty, T., 1978. Exploring the Interface between hierarchies, multiple objectives and the fuzzy sets. *Fuzzy Sets and Systems*, 1(1) 57-68. DOI: https://doi.org/10.1016/0165-0114(78)90032-5

Shitu, K. and Berhanu, S., 2020. Assessment of potential suitable surface irrigation area in Borkena River Catchment, Awash Basin, Ethiopia. *Journal of Water Resources and Ocean Science*, 9(5) 98-106. DOI: https://doi.org/10.11648/j.wros.20200905.12

Teshome, A. and Halefom, A., 2020. Potential land suitability identification for surface irrigation: In case of Gumara watershed, Blue Nile basin, Ethiopia. *Modeling Earth Systems and Environment*, 6, 929-942. DOI: https://doi.org/10.1007/s40808-020-00729-6

World Bank, 2006. Ethiopia: Managing water resources to maximize sustainable growth. *Washington DC, USA: A World Bank Water Resources Assistance Strategy for Ethiopia.*

Wubalem, A., 2021. GIS-based land suitability analysis for surface irrigation using analytical hierarchy process method in East and West Bellessa, Northwestern Ethiopia. DOI: https://doi.org/10.21203/rs.3.rs-768423/v1

*****