

Article

Assessment of Agricultural Land Suitability for Surface Irrigation Using Geospatial Techniques in the Lower Omo Gibe Basin, Ethiopia

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Abstract: Land suitability assessment for irrigation is critical to inform as well as manage current and future irrigated agriculture production systems. Land suitability analysis determines whether a given land area could potentially be used for specific crop production. The objective of this study was to identify the availability of suitable land for surface irrigation systems for the production of millet, sorghum, sugarcane, and wheat production in the Lower Omo Gibe plain, Southern Ethiopia. Land suitability analysis was performed by a parametric method using factors such as soil texture, effective soil depth, Calcium Carbonate (CaCO₃), soil electrical conductivity (ECe), drainage class, and slope. Five land suitability classes were identified that include highly suitable (S1), moderately suitable (S2), marginally suitable (S3), currently not suitable (N1), and permanently not suitable (N2). Results showed that 6.6, 7.5, 6.6, and 6.6% of the study area mostly located in the western part of the basin, were highly suitable (S1) for irrigated millets, sorghum, sugarcane, and wheat crops production, respectively. However, the mountainous areas in the central part of the basin were classified as N2 due to the steep slope and shallow soil depth. Overall, the results of the study revealed that the use of various suitability analysis techniques could assist in identifying suitable land for irrigated agriculture.

Keywords: parametric method; soil properties; surface irrigation; land suitability; Ethiopia



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1. Introduction

The concept of land evaluation refers to predicting the performance of land over time by considering the type of land use, as defined by Van Diepen [1] and Rossiter [2]. The strategic land-use decisions are then based on these predictions. Therefore, soil surveys are the primary basis for evaluating land. According to the Food and Agricultural Organization (FAO), suitability is based on crop requirements and land characteristics, measuring how well the characteristics of a land unit match the demands of a particular land use [3]. A

land suitability assessment is therefore a prerequisite to assessing agricultural production sustainably. Ethiopia has the second-largest population after Nigeria in Africa, and 79.6% of its people live in rural areas and rely primarily on low-productivity agriculture [4]. There are abundant water resources in Ethiopia; it receives about 980 billion m³ of rainwater each year [5,6]. According to Awulachew [7], 30 to 70 million ha of land could be cultivated. Awulachew [5] estimated Ethiopia's potential irrigable land to be 5.3 million ha, which includes 1.65 million ha that could be irrigated using groundwater or rainwater.

A parametric approach is proposed for identifying the suitability of land for irrigation and crop production based on soil physical and chemical parameters [8]. The soil properties and topography of a piece of land determine its suitability for irrigation. Researchers have used parametric systems to evaluate land suitability for surface, sprinkler, and drip irrigation, as well as for different crops in different watersheds. Lanfredi and Ronchi [9] used a parametric methodology similar to [8] for examining the suitability of land for rain-fed agriculture in Kilte Awlaelo, Tigray, Ethiopia. Based on the literature and the opinions of experts, factors that affect irrigation land suitability for surface irrigation have been identified. The climatic requirements of the selected crops, such as precipitation, mean temperature, and relative humidity during the growing cycle, are some of several factors to be taken into account [8,10,11]. Land characteristics include physical soil characteristics including texture, coarse fragment, soil depth, CaCO₃, gypsum, and soil fertility features like apparent ECE, base saturation, sum of basic cations, PH, organic carbon, as well as salinity and alkalinity. Factors that affect the suitability of an area for surface irrigation were identified and used for this study. These factors are important for the growth and development of crops and farm management. Landform variables such as soil depth, slope, drainage class texture, calcium carbonate (CaCO₃), electrical conductivity (EC), and pH were used to generate a map describing the suitability of land to irrigate crops such as barley, teff, millet, sorghum, wheat, maize, peas, beans, chickpeas, and groundnuts. A parametric land evaluation approach was used by Gebremariam and Zhang [12] to evaluate rain-fed crop production in Tigray, Ethiopia. According to the study, topographic constraints mainly affect the suitability of land for cultivation. Their study area had moderate to steep slopes and escarpments as well as shallow soils that were unsuitable for retaining moisture. A study by Mahari and Alebachew [13] evaluated the suitability of soil properties in the Bicheat watershed of Dejen district, Ethiopia, for irrigation. Parametric methods were used to evaluate soil properties such as texture, depth, EC, drainage, CaCO₃ content, and slope of the study area. A steep slope, gravelly soil texture, and shallow depth of soil made 120 ha of land permanently unsuitable.

Albaji and Alboshokeh [14] carried out a land suitability evaluation study in the Fakkeh region, southwest Iran, for key crops such as wheat, alfalfa, maize, and barley, covering 43,700 ha was undertaken by using a parametric method. In their investigation, a physical property of the soil, especially light soil texture, was the most significant limiting factor in the production of wheat, alfalfa, and barley. Similarly, In Fars province in southern Iran, Azadi and Baghernejad [15] used a parametric approach to evaluate land suitability for wheat and sugar beet cultivation in 15,000 ha of land. Due to relative humidity limitations caused by the growing cycle, their study showed that the area is moderately suitable for wheat and highly suitable for sugar beet. They suggested a modification of climatic suitability since the mean temperature during the growth cycle is the main limiting factor for irrigated wheat. Mathewos et al. [16] evaluated the land suitability of Bilate Alaba sub-watershed for maize, sorghum, and wheat production under rainfed conditions. A maximum limitation and parametric methods were used to determine land suitability categories. An approach for evaluating the suitability of a watershed for surface irrigation was used by Weldeabzgi et al. [17]. As a result of the land suitability evaluation, a total area of 3064 ha (72.6%) was marginally suitable, while 1154 ha (27.4%) were currently unsuitable. In addition to land suitability for crop cultivation analysis, many researchers have applied a parametric land evaluation approach to different irrigation methods for their area of interest [18–24].

A large irrigation command area in the southern part of Ethiopia, the lower Omo Gibe basin is under development for sugarcane production to supply the sugar factories. The government also plans to irrigate the area with wheat. Therefore, it was essential to evaluate the suitability of the land for major crops in this region. The major grains, maize, wheat, and sorghum have long contributed to food security in Ethiopia [25] and mostly grown in the highland parts of the country [26]. In order to inform future land allocation and development planning in the lower Omo Gibe basin, southern Ethiopia, this study evaluated and compared land suitability for surface irrigation-based production of millet, sorghum, sugarcane, and wheat. A combination of geographical information system (GIS) and parametric methods was used.

2. Materials and Methods

2.1. Description of the Study Area

The study was carried out in the lower Omo Gibe basin in southern Ethiopia. The basin is located between latitude $5^{\circ}17'12''$ to $6^{\circ}24'15''$ N and longitude $35^{\circ}37'15''$ to $36^{\circ}4'30''$ E. The area of the watershed is 2530 km^2 , and elevations range between 368 and 807 m a.m.s.l (Figure 1). According to rainfall data collected from the meteorological stations within the study area, the basin receives on average 972 mm per year of rainfall, with deficient rainfall in months of December to February. The average minimum and maximum monthly temperatures in the study area were 18.8°C and 35.5°C , respectively. The annual mean temperature of the watershed is 26.8°C (Figure 2).

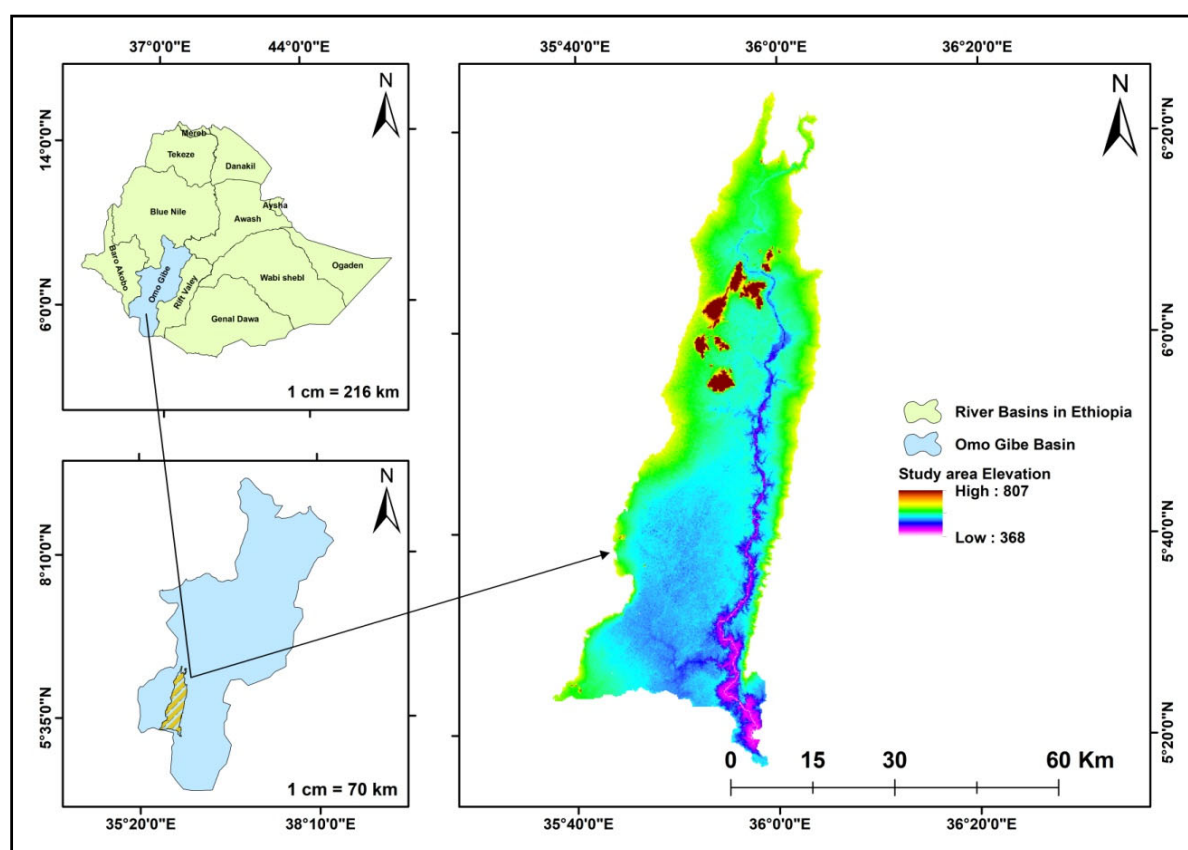


Figure 1. Location of the study area in relation to river basins in Ethiopia and the Omo-Gibe basin.

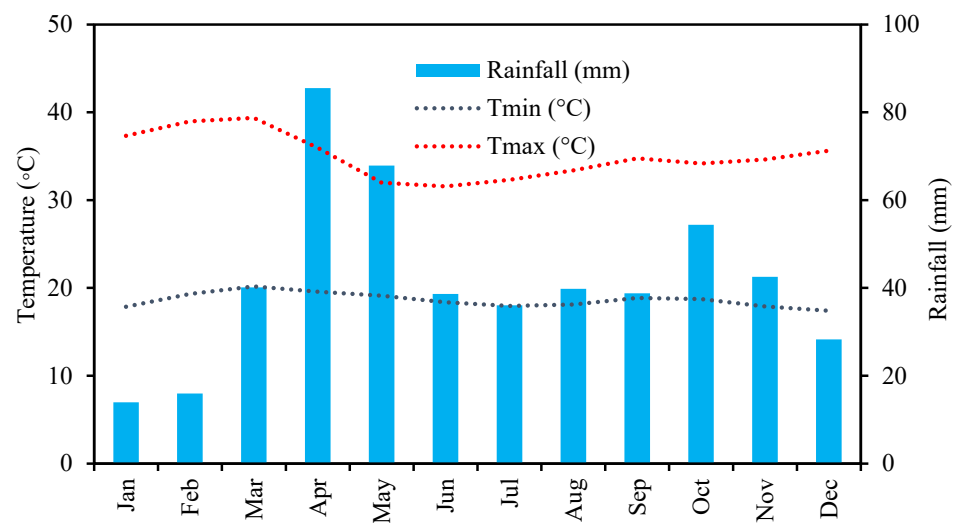


Figure 2. Monthly mean minimum and maximum temperatures, as well as monthly mean rainfall records, are based on observations from 1981 to 2020.

The study area is characterized mainly by gentle land features. The major soil types of the study area are Chromic Luvisols, Eutric Leptosols, Eutric Fluvisols, Eutric Vertisols, Lithic Leptosols, Sodic Solonchaks, and Petric Gypsisols. The major land uses of the watershed are forest land (57.7%), cropland (16.9%), shrub land (15.5%), grassland (7.6%), and the remaining (2.3%) of land is covered with water bodies, flooded vegetation, built-up area, and bare land (Figure 3).

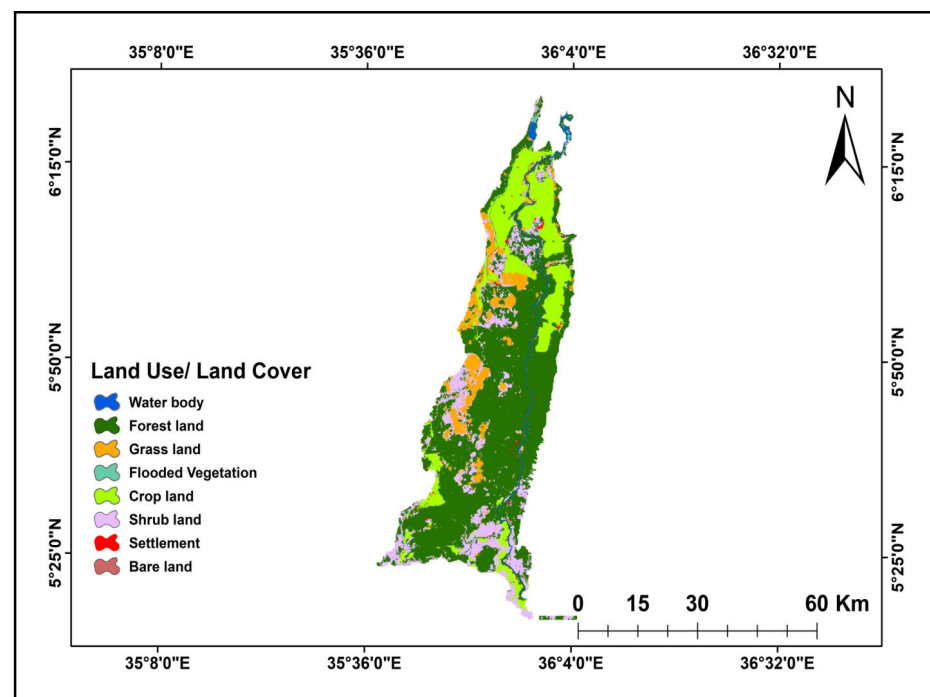


Figure 3. Land use/land cover types of the study area.

Surface irrigation is widely practiced in the study area. A surface irrigation system has been constructed along the Omo and Sharman rivers to meet the crop water needs during the summer and winter seasons by constructing headwork structure across the rivers. A large portion of this area is irrigated for sugarcane cultivation. In addition to wheat, sorghum, millets, barley, and maize, irrigation is planned for these crops.

2.2. Data Collection and Analysis

The study used soil data from Ethiopia's Ministry of Water and Energy, the harmonized world soil database (HWSD) v1.2, and a digital elevation model with a spatial resolution of 12.5 m obtained from <https://search.asf.alaska.edu/> accessed on 10 June 2022 for slope analysis. The land use/land cover map was downloaded from <https://livingatlas.arcgis.com/landcover/> accessed on 5 June 2022 and had a 10 m resolution.

Analysis was conducted for each physical land suitability factor to evaluate the suitability of the suggested land for surface irrigation after the necessary data had been gathered from different sources. The major land suitability analysis factors considered for irrigation-based crop production in this study were slope, drainage properties, texture, effective soil depth, CaCO₃ status, and EC. A weighted assessment of each factor was conducted to identify suitable areas for surface irrigation. Data analysis was done in Microsoft Excel 2019 (Microsoft Office, Redmond, WA, USA) based on the rating scale of topographic and soil requirements for the selected crops [8].

2.3. Suitability Assessment Method

To determine land suitability classes, the FAO method recommends the parametric method procedure stated by Sys et al. [8] was used based on selected crop requirements and measured landscape and soil parameters (Table 1). A soil's capacity to retain water is strongly influenced by its capacity to drain, the amount of organic carbon present, and the texture of the soil [27]. Based on their ability to retain water, four different types of soil textures were identified: very high holding capacity (silt, silt loam, and silty clay loam), high holding capacity (silty clay and clay), low holding capacity (loamy sands), and very low holding capacity (e.g., sands). The hydraulic conductivity of the soil is influenced by a variety of factors. According to Benson and Daniel [28], the soil composition, permeant properties, void ratio, structure, and degree of saturation during permeation were the five variables that had the most influence on hydraulic conductivity. Several land characteristics were combined in this model, including physical and chemical soil characteristics (texture, depth, CaCO₃, pH, and EC), topography (slope), and wetness characteristics (drainage) to identify land suitability. Based on the workflow shown in Figure 4, land suitability maps were created for the 21 soil mapping units using ArcGIS 10.3.1.

Table 1. Topographic and soil requirements—Wheat, sugarcane, sorghum, and millets [8].

Land Characteristics	Class, Degree of Limitation and Rating Scale					
	0	1	2	3	4	5
Wheat						
Topography (t)						
Slope (%) (1)	0–1	1–2	2–4	4–6	-	>6
(2)	0–2	2–4	4–8	8–16	-	>16
(3)	0–4	4–8	8–16	16–30	-	>30
Wetness (w)						
Drainage (4)	good	moderate	imperfect	poor and aeric	poor, but drainable	poor, not drainable
(5)	imperfect	moderate	good			
Physical soil characteristics (s)						
Texture/Structure	C < 60s, SiC, Co, SiL, CL	C < 60v, SC, C > 60s, L	C > 60v, SCL	SL, LfS	-	Cm, SiCm, LcS, Fs, cS
Soil depth (cm)	>90	90–50	50–20	20–10	-	<10
CaCO ₃ (%)	3–20	20–30	30–40	40–60	-	>60
Soil fertility characteristics (f)						
pH H ₂ O	7.0–6.5, 7.0–7.5	6.5–6.0, 7.5–8.2	6.0–5.6, 8.2–8.3	5.6–5.2, 8.3–8.5	<5.2	>8.5
Salinity and Alkalinity (n)						
EC (dS/m)	0–1	1–3	3–5	5–6	6–10	>10

Table 1. Cont.

Land Characteristics	Class, Degree of Limitation and Rating Scale					
	S1	S2	S3	N1	N2	
	0	1	2	3	4	
Sugarcane						
Topography (t)						
Slope (%) (1)	0–1	1–2	2–4	4–6	-	>6
(2)	0–2	2–4	4–8	8–16	-	>16
(3)	0–4	4–8	8–16	16–30	30–50	>50
Wetness (w)						
Drainage (4)	good	moderate	imperfect	poor and aeric	poor, but drainable	poor, not drainable
(5)	imperfect	moderate	good			
Physical soil characteristics (s)						
Texture/Structure	C < 60s, Co, SiC, SiCL, Si, SiL, CL	C < 60v, SC, C > 60s, L, SCL	C > 60v, SL, LfS, LS	fS, LcS	-	Cm, SiCm, S, cS
Soil depth (cm)	>125	125–80	80–50	50–20	-	<20
CaCO ₃ (%)	0–12	12–25	25–35	35–50	-	>50
Soil fertility characteristics (f)						
pH H ₂ O	6.5–6.0, 6.5–7.0	6.0–5.5, 7.0–7.5	5.5–5.0, 7.5–8.0	5.0–4.5, 8.0–8.5	<4.5	>8.5
Salinity and Alkalinity (n)						
EC (dS/m)	0–2	2–5	5–8	8–10	10–14	>14
Sorghum						
Topography (t)						
Slope (%) (1)	0–1	1–2	2–4	4–6	-	>6
(2)	0–2	2–4	4–8	8–16	-	>16
(3)	0–4	4–8	8–16	16–30	30–50	>50
Wetness (w)						
Drainage (4)	good	moderate	imperfect	poor and aeric	poor, but drainable	poor, not drainable
(5)	imperfect	moderate	good			
Physical soil characteristics (s)						
Texture/Structure	C < 60s, SiC, Co, SiL, SiCL, Si, SC	C < 60v, C > 60s, L, SCL	C > 60v, SL, LfS, LS	fS, S, LcS	-	Cm, SiCm, Cs
Soil depth (cm)	>90	90–50	50–20	20–10	-	<10
CaCO ₃ (%)	0–10	20–30, 0–2	30–45	45–75	-	>75
Soil fertility characteristics (f)						
pH H ₂ O	6.5–6.0, 6.5–7.0	6.0–5.5, 7.0–8.2	5.5–5.3, 8.2–8.3	5.3–5.2, 8.3–8.5	<5.2	>8.5
Salinity and Alkalinity (n)						
EC (dS/m)	0–4	4–8	8–12	12–16	16–20	>20
Millets						
Topography (t)						
Slope (%) (1)	0–1	1–2	2–4	4–6	-	>6
(2)	0–2	2–4	4–8	8–16	-	>16
(3)	0–4	4–8	8–16	16–30	30–50	>50
Wetness (w)						
Drainage (4)	good	moderate	imperfect	poor and aeric	poor, but drainable	poor, not drainable
(5)	imperfect	moderate	good			
Physical soil characteristics (s)						
Soil texture	C < 60s, Co, SiCL, SC, L, SiCs	C < 60v, C > 60s, SL, SCL	C > 60v, LfS, LS	Cm, SiCm, LcS, Fs, S	-	cS
Soil depth (cm)	>90	90–50	50–20	20–10	-	<10
CaCO ₃ (%)	0–10	20–25	25–35	35–50	-	>50
Soil fertility characteristics (f)						
pH H ₂ O	6.5–6.0, 6.5–7.0	6.0–5.6, 7.0–7.6	5.6–5.4, 7.6–8.0	5.4–5.2, 8.0–8.2	<5.2	>8.2
Salinity and Alkalinity (n)						
EC (dS/m)	0–2	2–4	4–6	6–8	8–12	>12

Note(s): Where (1) Irrigated agriculture, (2) full mechanization, (3) low level of management, (4) medium and fine textured soils, (5) coarse-textured soils (sandy families). Cm: massive clay; SiCm: massive silty clay; C > 60, v: very fine clay, vertisol structure; C > 60, s: very fine clay, blocky structure; C < 60, v: clay, vertisol structure; c < 60, s: clay, blocky structure; SiCs: silty clay, blocky structure; Co: clay, oxisol structure; SiCL: silty clay loam; CL: clay loam; Si: silt; SiL: silt loam; SC: sandy clay; L: loam; SCL: sandy clay loam; SL: sandy loam; LfS: loamy fine sand; LS: loamy sand; LcS: loamy coarse sand; fS: fine sand; S: sand; cS: coarse sand; CaCO₃: Calcium carbonate; EC: Electrical conductivity; S1: highly suitable; S2: moderate suitable; S3: marginal suitable; N1: currently not suitable and N2: permanently not suitable.

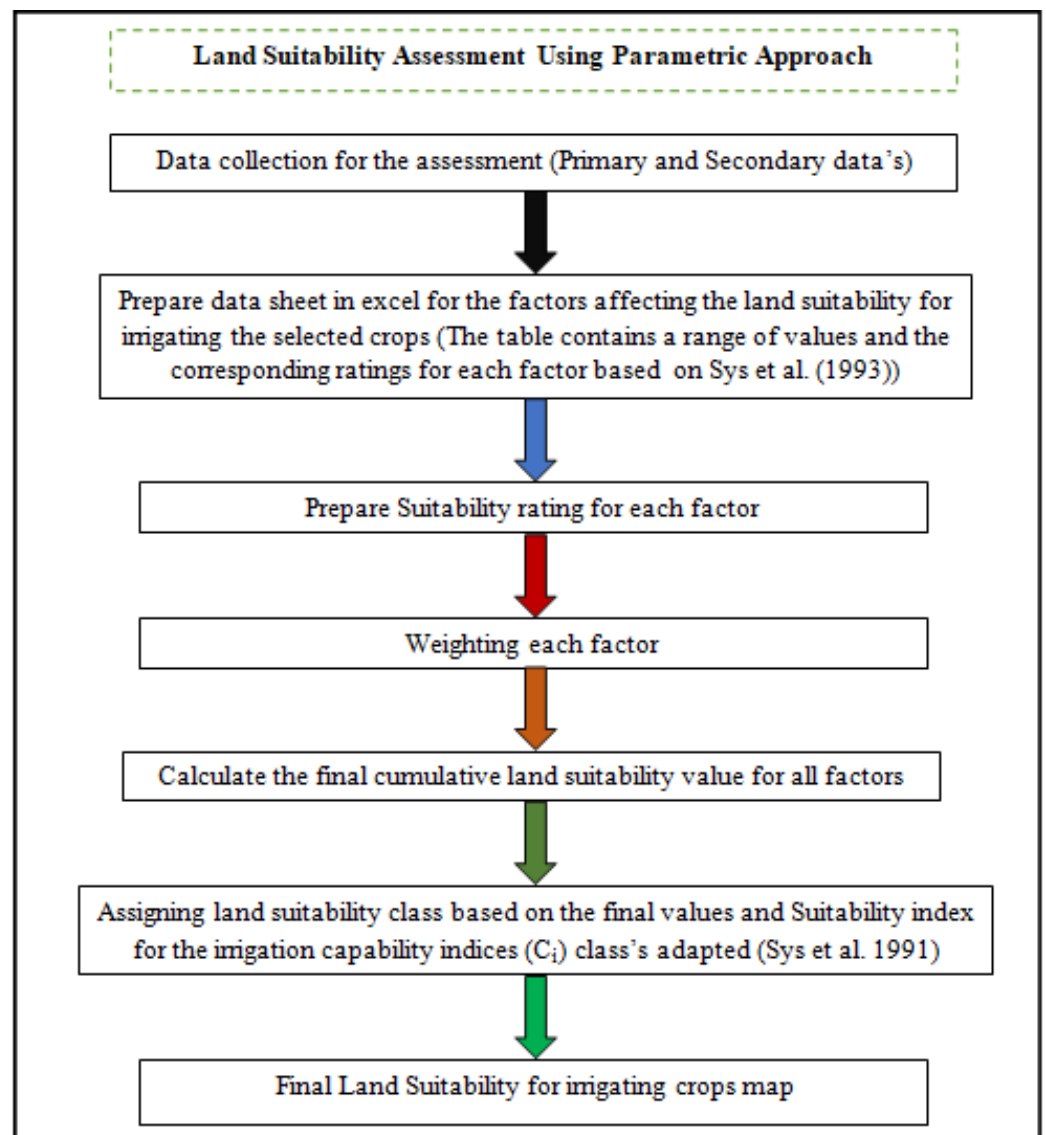


Figure 4. Flow chart of parametric approach for assessing land suitability for irrigating crops.

Soil and topographic factors are considered on a numerical scale ranging from 0 to 100%, attributes having certain limitation gets a low rate up, and a high rate is assigned to the most appropriate attribute, which corresponds to a suitability rating based on a parametric evaluation method. The Storrie method provides this index as a multiplicative of each characteristic [29], and it is mathematically expressed in (Equation (1)) as follows:

$$C_i = A \times \frac{B}{100} \times \frac{C}{100} \times \frac{D}{100} \times \frac{E}{100} \times \frac{F}{100}. \quad (1)$$

where: C_i represents the irrigation suitability index, A represents the soil texture rating, B represents the soil depth rating, C represents the CaCO_3 status rating, D represents the electro conductivity rating, E represents the drainage rating, and F represents the slope rating. The value of the capability index is used to determine suitability categories (Table 2).

Table 2. Suitability index for the irrigation capability indices (Ci) classes [30].

Capability Index	Class	Definition	Symbol
>80	I	Highly Suitable	S1
60–80	II	Moderate Suitable	S2
45–60	III	Marginal Suitable	S3
30–45	IV	Currently not suitable	N1
<30	V	Permanently not suitable	N2

3. Results and Discussion

3.1. Suitability of Thematic Maps

The land suitability maps for different crops were prepared based on a parametric approach using a digital soil map. The topography and soil characteristics of the study area allowed the detection of 21 soil series. Table 3 shows topographic characteristics such as slope and soil properties such as soil texture, effective soil depth, salinity, drainage, and calcium carbonate content (Figure 5).

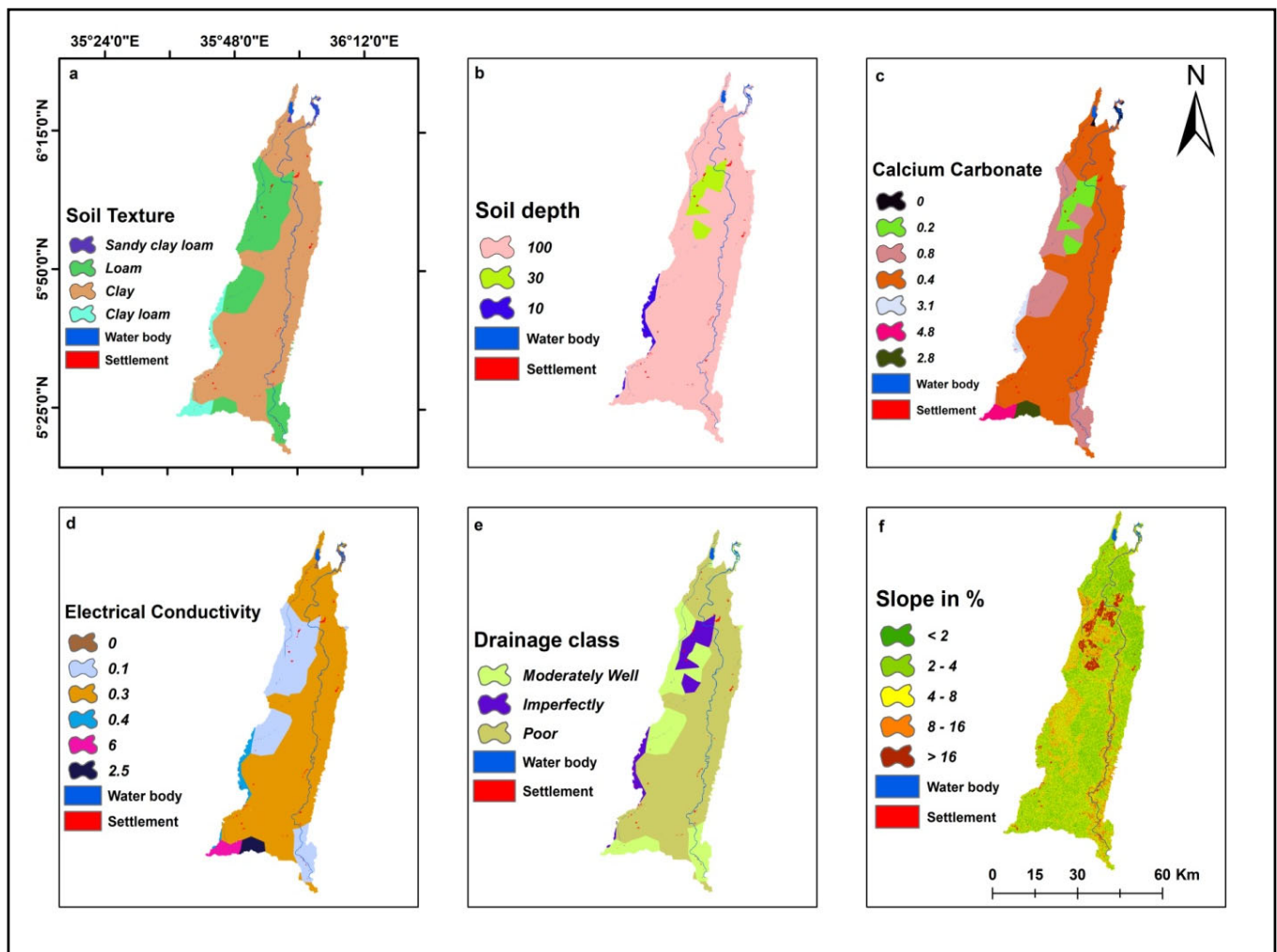


Figure 5. Topography and soil physical and chemical properties of the study area: (a) Soil texture, (b) Soil Depth (cm), (c) Calcium Carbonate (CaCO_3) (%), (d) Electrical Conductivity (dS m^{-1}), (e) Drainage class, and (f) Slope (%).

Table 3. The study area's soil physicochemical parameters.

Code of Land Series	Soil Type	Soil Type	Depth (cm)	CaCO ₃ (%)	EC (dS m ⁻¹)	Drainage	Slope (%)
1	Eutric Fluvisols	Loam	100	0.8	0.1	Moderately Well	<2
2	Eutric Fluvisols	Loam	100	0.8	0.1	Moderately Well	2–4
3	Eutric Fluvisols	Loam	100	0.8	0.1	Moderately Well	4–8
4	Eutric Fluvisols	Loam	100	0.8	0.1	Moderately Well	8–16
5	Petric Gypsisols	Loam	100	2.8	2.5	Moderately Well	<2
6	Petric Gypsisols	Loam	100	2.8	2.5	Moderately Well	4–8
7	Eutric Leptosols	Loam	30	0.2	0.1	Imperfectly	<2
8	Eutric Leptosols	Loam	30	0.2	0.1	Imperfectly	4–8
9	Eutric Leptosols	Loam	30	0.2	0.1	Imperfectly	>16
10	Lithic Leptosols	Clay loam	10	3.1	0.4	Imperfectly	<2
11	Lithic Leptosols	Clay loam	10	3.1	0.4	Imperfectly	4–8
12	Chromic Luvisols	Sandy clay loam	100	0	0	Moderately Well	<2
13	Chromic Luvisols	Sandy clay loam	100	0	0	Moderately Well	4–8
14	Sodic Solonchaks	Clay loam	100	4.8	6	Moderately Well	<2
15	Sodic Solonchaks	Clay loam	100	4.8	6	Moderately Well	2–4
16	Sodic Solonchaks	Clay loam	100	4.8	6	Moderately Well	4–8
17	Eutric Vertisols	Clay	100	0.4	0.3	Poor	<2
18	Eutric Vertisols	Clay	100	0.4	0.3	Poor	2–4
19	Eutric Vertisols	Clay	100	0.4	0.3	Poor	4–8
20	Eutric Vertisols	Clay	100	0.4	0.3	Poor	8–16
21	Eutric Vertisols	Clay	100	0.4	0.3	Poor	>16

3.1.1. Soil Physical Properties

Clay is the dominant textural class in the basin, covering 71.2% of the land area. A clay soil texture is highly suitable for wheat, sugarcane, sorghum, and millet production according to Sys et al. [8] landscape and soil requirements guideline, followed by 24.9, 3.3, and 0.52% of loam, clay loam, and sandy clay loam, respectively (Figure 5a). The soil texture influences soil pore spaces, as well as the soil permeability and infiltration rate, which are important factors in soil physical analysis for surface irrigation suitability evaluation [31].

In the study area, soil depth varies from 10 to 100 cm (Figure 5b). as per African Geological map data base Quaternary sediments, Tertiary extrusive and intrusive rock, and Tertiary are the geological features of the study area below the topsoil depth, with respective area coverage of 2162.1 km², 275.8 km², and 91.7 km². Moreover, soil depth plays a significant role in determining whether a farm is suitable for surface irrigation. Surface irrigation is beneficial for deep soils since they have an impact on crop rooting depth. With soil depths of 100 cm, Eutric Fluvisols, Petric Gypsisols, Chromic Luvisols, Sodic Solonchaks, and Eutric Vertisols occur in the study area. On the other hand, Eutric Leptosols and Lithic Leptosols were located 30 and 10 cm below the surface, respectively. As shown in Table 3, the soil drainage in the basin was classified as moderately well-drained, poorly drained, and imperfectly drained (Figure 5e). For evaluating surface irrigation suitability, soil drainage is also an influential factor because it handles excess water on the surface. Without this continuous leaching, salt may build up to levels that may be harmful to the landscape and crops. Proper drainage of a specific area is essential to allow the continuous movement of water and salt through the profile [32].

3.1.2. Soil Chemical Properties

According to Figure 5d, salinity values ranged from 0 to 6 Ds m⁻¹ in the study area which shows highly suitable for sorghum, moderate suitable for sugarcane and millets, and marginal suitable for wheat (Table 1). Average soil calcium carbonate (CaCO₃) values ranged from 0 to 4.8%. The highest CaCO₃ value of 4.8% was observed in land series coded

14, 15, and 16, and the lowest 0% was recorded in land series coded 12 and 13 (Figure 5c). Despite the fact that calcium carbonate (CaCO_3) levels vary across the study area, the range is considered highly suitable for all selected crops.

3.1.3. Slope Evaluation for Growing Field Crops

There are three types of land management methods at the farm level: (1) irrigated agriculture, (2) full mechanization, and (3) low management. By producing a slope suitability map for the full mechanization category in this study, topographic suitability for the cultivation of the selected crops was determined. As shown in (Figure 5f), the slope map was divided into five classes based on the topographic requirement for mechanized surface irrigation as flat (0–2%), gently sloping (2–4%), moderately steep (4–8%), steep (8–16%), and very steep (>16%). Accordingly, the entire watershed has been classified as flat (Land series coded—1, 5, 7, 10, 12, 14, and 17), gentle (Land series coded—2, 15, and 18), moderately steep (Land series coded—3, 6, 8, 11, 13, 16, and 19), steep (Land series coded—4, and 20), and very steep (Land series coded—9, and 21). Thus, surface irrigation is effective in 22.7% of the watershed due to flat and gentle slopes. The slope of a land surface describes its steepness, and it is an influential characteristic of terrain. The slope plays a significant role in plants' growth, according to Mohammad et al. [33]. Thus, topography directly affects runoff response and soil infiltration rates. Further, they found that a higher slope reduces rainwater infiltration and recharges groundwater by letting more water flow through the topsoil.

3.1.4. Soil Suitability Evaluation for Growing Field Crops

Tables 4–6 show the results of a land suitability analysis for surface irrigation using the parametric evaluation method. The selected crops have a high potential for production under irrigation as long as the irrigation water requirements are met. In total, 6.6, 6.6, 7.5, and 6.6% of the study area are highly suitable (S1) for growing wheat, sugarcane, sorghum, and millets. The moderately suitable regions cover a comparatively higher percentage of wheat, sugarcane, sorghum, and millets than highly suitable regions, with 9.2, 9.7, 10, and 11.3%, respectively. There are 42.5, 68.7, 41.5, and 41.1% of the total studied area that are marginally suitable for growing irrigated wheat, sugarcane, sorghum, and millets, respectively. Furthermore, 35.2, 7.8, 35.5, and 35.5% of the study area are currently unsuitable for irrigating wheat, sugarcane, sorghum, and millets, respectively. Approximately 4.4, 5.0, 3.4, and 3.4% of the total land area is permanently unsuitable for wheat, sugarcane, sorghum, and millets.

Table 4. The Ci values and suitability classes of surface irrigation for each land series using the parametric land suitability analysis method [29].

Code of Land Series	Wheat		Sugarcane		Sorghum		Millets	
	LCI	SC	LCI	SC	LCI	SC	LCI	SC
1	85.7	S1	81.5	S1	90.3	S1	90.3	S1
2	81.5	S1	77.4	S1	85.7	S1	85.7	S1
3	72.9	S2t	69.2	S2t	76.7	S2t	76.7	S2t
4	51.4	S3t	48.9	S3t	54.2	S3t	54.2	S3t
5	85.7	S1	85.7	S1	90.3	S1	90.3	S1
6	72.9	S2t	72.9	S2t	76.7	S2t	76.7	S2t
7	68.6	S2sw	48.5	S3sw	68.6	S2sw	72.3	S2sw
8	58.3	S3swt	41.2	N1swt	58.3	S3swt	61.4	S2swt
9	17.2	N2swt	12.1	N2swt	17.2	N2swt	18.1	N2swt
10	34.0	N1sw	21.3	N2sw	48.5	S3sw	48.5	S3sw

Table 4. Cont.

Code of Land Series	Wheat		Sugarcane		Sorghum		Millets	
	LCI	SC	LCI	SC	LCI	SC	LCI	SC
11	28.9	N2swt	18.1	N2swt	41.2	N1swt	41.2	N1swt
12	80.8	S1	85.7	S1	90.3	S1	90.3	S1
13	68.6	S2st	72.9	S2st	76.7	S2t	76.7	S2t
14	57.0	S3n	76.7	S2n	85.7	S1	54.2	S3n
15	54.2	S3n	72.9	S2n	81.5	S1	51.4	S3n
16	48.5	S3nt	65.2	S2nt	72.9	S2t	46.0	S3nt
17	51.0	S3sw	54.2	S3sw	51.0	S3sw	51.0	S3sw
18	48.5	S3sw	51.4	S3sw	48.5	S3sw	48.5	S3sw
19	43.4	N1swt	46.0	S3swt	43.4	N1swt	43.4	N1swt
20	30.6	N1swt	32.5	N1swt	30.6	N1swt	30.6	N1swt
21	12.8	N2swt	13.5	N2swt	12.8	N2swt	12.8	N2swt

Note(s): Where, LCI, SC, n, s, t, and w represent land capability index, suitability class, salinity and alkalinity, physical properties of soil, topography, and drainage.

Table 5. Suitability for surface irrigation of wheat, sugarcane, sorghum, and millets distribution.

Suitability	Wheat			Sugarcane			Sorghum			Millets		
	Land Series	Area (km ²)	Ratio (%)	Land Series	Area (km ²)	Ratio (%)	Land Series	Area (km ²)	Ratio (%)	Land Series	Area (km ²)	Ratio (%)
S1	1, 2, 5 and 12	167.6	6.6	1, 2, 5 and 12	167.6	6.6	1, 2, 5, 12, 14 and 15	188.9	7.5	1, 2, 5 and 12	167.1	6.6
S2	3, 6, 7 and 13	231.5	9.2	3, 6, 13, 14, 15 and 16	244.8	9.7	3, 6, 7, 13 and 16	253.5	10.0	3, 6, 7, 8 and 13	285.3	11.3
S3	4, 8, 14, 15, 16, 17 and 18	1075.5	42.5	4, 7, 17, 18 and 19	1739.0	68.7	4, 8, 10, 17 and 18	1049.8	41.5	4, 10, 14, 15, 16, 17 and 18	1039.8	41.1
N1	10, 19 and 20	891.4	35.2	8 and 20	197.1	7.8	11, 19 and 20	896.9	35.5	11, 19 and 20	896.9	35.5
N2	9, 11 and 21	110.0	4.4	9, 10, 11 and 21	127.7	5.0	9 and 21	87.0	3.4	9 and 21	87.0	3.4
* Mis Land	-	53.98	2.1	-	53.98	2.1	-	53.98	2.1	-	53.98	2.1
Total	-	2530	100.0	-	2530	100.0	-	2530	100.0	-	2530	100.0

Note(s): Miscellaneous Land: (Settlement and Water bodies) *.

Table 6. The land series corresponding to crop and suitability class for a different composition.

Crops-Suitability-Land Series	S1	Area (km ²)	S2	Area (km ²)	S3	Area (km ²)	N1	Area (km ²)	N2	Area (km ²)
Wheat only	-	-	-	-	-	-	10	17.6	-	-
Sugarcane only	-	-	14 and 15	21.8	7 and 19	760.6	8	53.8	10	17.6
Sorghum only	14 and 15	21.8	-	-	-	-	-	-	-	-
Millets only	-	-	8	53.8	-	-	-	-	-	-
For all crops	1, 2, 5 and 12	167.1	3, 6 and 13	214.5	4, 17 and 18	1009.4	20	153.2	9 and 21	87.0
Wheat-Sugarcane	1, 2, 5 and 12	167.1	3, 6 and 13	214.5	4, 17 and 18	1009.4	20	153.2	9, 11 and 21	110.0
Wheat-Sorghum	1, 2, 5 and 12	167.1	3, 6, 7 and 13	241.5	4, 8, 17 and 18	1063.2	19 and 20	886.8	9 and 21	87.0
Wheat-Millets	1, 2, 5 and 12	167.1	3, 6, 7 and 13	241.5	4, 14, 16, 17 and 18	1042.0	19 and 20	886.8	9 and 21	87.0

Table 6. Cont.

Crops-Suitability-Land Series	S1	Area (km ²)	S2	Area (km ²)	S3	Area (km ²)	N1	Area (km ²)	N2	Area (km ²)
Sugarcane-Sorghum	1, 2, 5 and 12	167.1	3, 6, 13 and 16	236.0	4, 17 and 18	1009.4	20	153.2	9 and 21	87.0
Sugarcane-Millet	1, 2, 5 and 12	167.1	3, 6 and 13	214.5	4, 17 and 18	1009.4	20	153.2	9 and 21	87.0
Sorghum-Millet	1, 2, 5 and 12	167.1	3, 6, 7 and 13	241.5	4, 10, 17 and 18	1027.0	11, 19 and 20	909.9	9 and 21	87.0
Wheat-Sugarcane-Sorghum	1, 2, 5 and 12	167.1	3, 6 and 13	214.5	4, 17 and 18	1009.4	20	153.2	9 and 21	87.0
Wheat-Sorghum-Millet	1, 2, 5 and 12	167.1	3, 6, 7 and 13	241.5	4, 17 and 18	1009.4	19 and 20	886.8	9 and 21	87.0
Sugarcane-Sorghum-Millet	1, 2, 5 and 12	167.1	3, 6 and 13	214.5	4, 17 and 18	1009.4	20	153.2	9 and 21	87.0

3.2. Land Suitability for Crops

As shown in Figure 6 and Table 5, land series coded 1, 2, 5, and 12 (167.1 km², 6.6%) have high suitability for all studied crops, while land series coded 14 and 15 (21.83 km², 0.9%) are highly suitable for only sorghum. Land series coded 3, 6, and 13 (214.5 km², 8.5%) show moderate suitability for all studied crops (wheat, sugarcane, sorghum, and millets), and land series coded 14, and 15 (21.8 km², 0.86%) indicate moderate suitability for sugarcane only. Land series 8 (53.8 km², 2.13%) exhibits moderate suitability for millets only. Land series coded 3, 6, 13, and 16 (235.9 km², 9.3%) exhibit moderate suitability for sugarcane and sorghum. Land series coded 3, 6, 7, and 13 (241.5 km², 9.5%) show moderate suitability for wheat, sorghum, and millets.

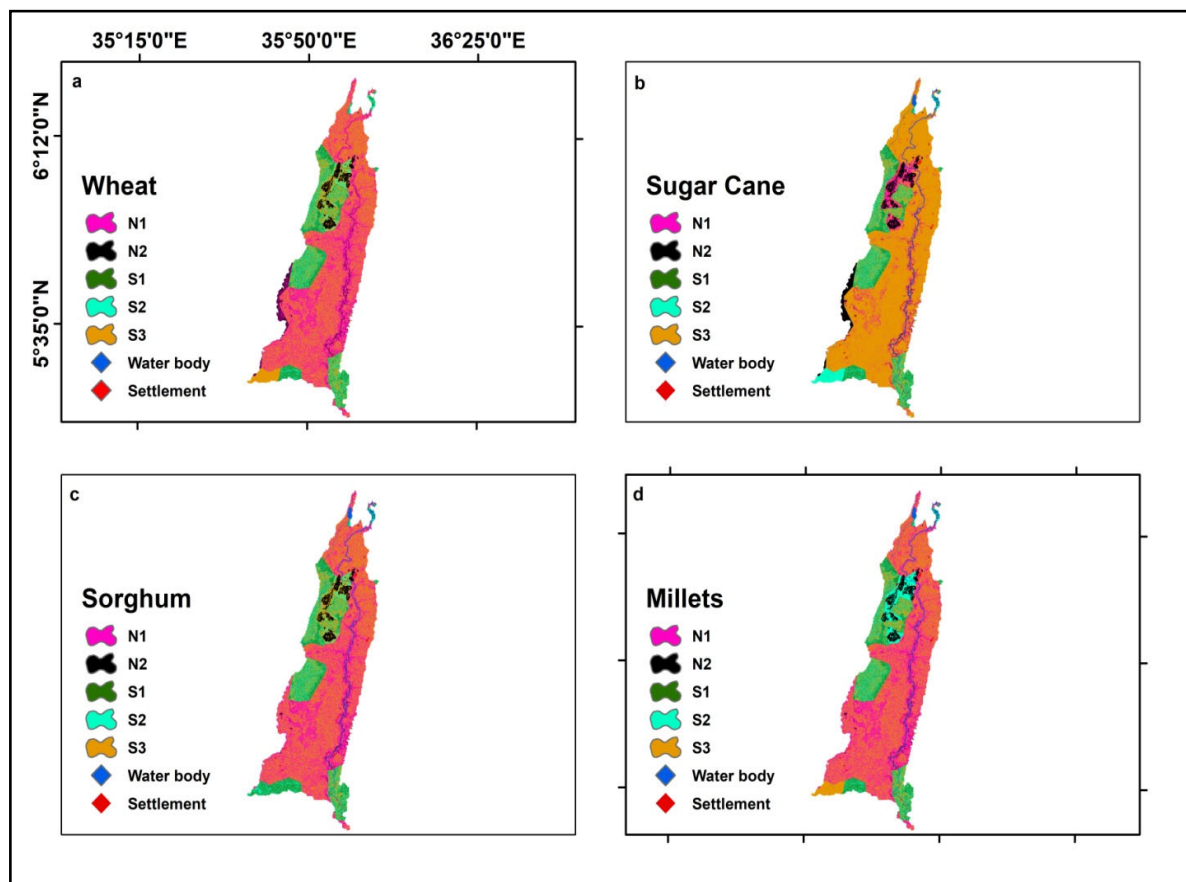


Figure 6. Land suitability map classes for (a) Wheat, (b) Sugarcane, (c) Sorghum, and, (d) Millets.

Land series coded 4, 17, and 18 (1009.4 km², 39.9%) show marginal suitability for all crops, Series coded 7 and 19 (760.6 km², 30.1%) show marginal suitability for sugarcane only, and Land series coded 4, 8, 17, and 18 (1063.3 km², 42.2%) show marginal suitability for wheat and sorghum. Land series coded 4, 14, 16, 17, and 18 covering (1041.9 km², 41.2%) are marginally suitable for wheat and millets. Similarly, land series coded 4, 10, 17, and 18 (1026.9 km², 40.6%) demonstrate marginal suitability for sorghum and millets. Land series coded 20 (153.2 km², 6.1%) exhibits low suitability (not suitable for all crops currently). Land series coded 10 (17.6 km², 0.7%) exhibits low suitability (currently unsuitable) for wheat only. Land in series coded 8 (53.8 km², 2.1%) shows low suitability (currently unsuitable) only for sugarcane. In addition, land series coded 11, 19, and 20, which cover (909.9 km², 35.9%), exhibit low suitability (currently not suitable) for sorghum and millets, and Land series coded 19 and 20 (886.8 km², 35.1%) exhibit low suitability (currently not suitable) for wheat, sorghum, and millets. Finally, land series coded 9 and 21 (86.9 km², 3.4%) are permanently unsuitable for all crops (Figure 7). Land series coded 10 (17.6 km², 0.7%) is permanently unsuitable for all crops, and land series coded 9, 11, and 21 (110.0 km², 4.4%) are permanently unsuitable for wheat and sugarcane (Tables 5 and 6).

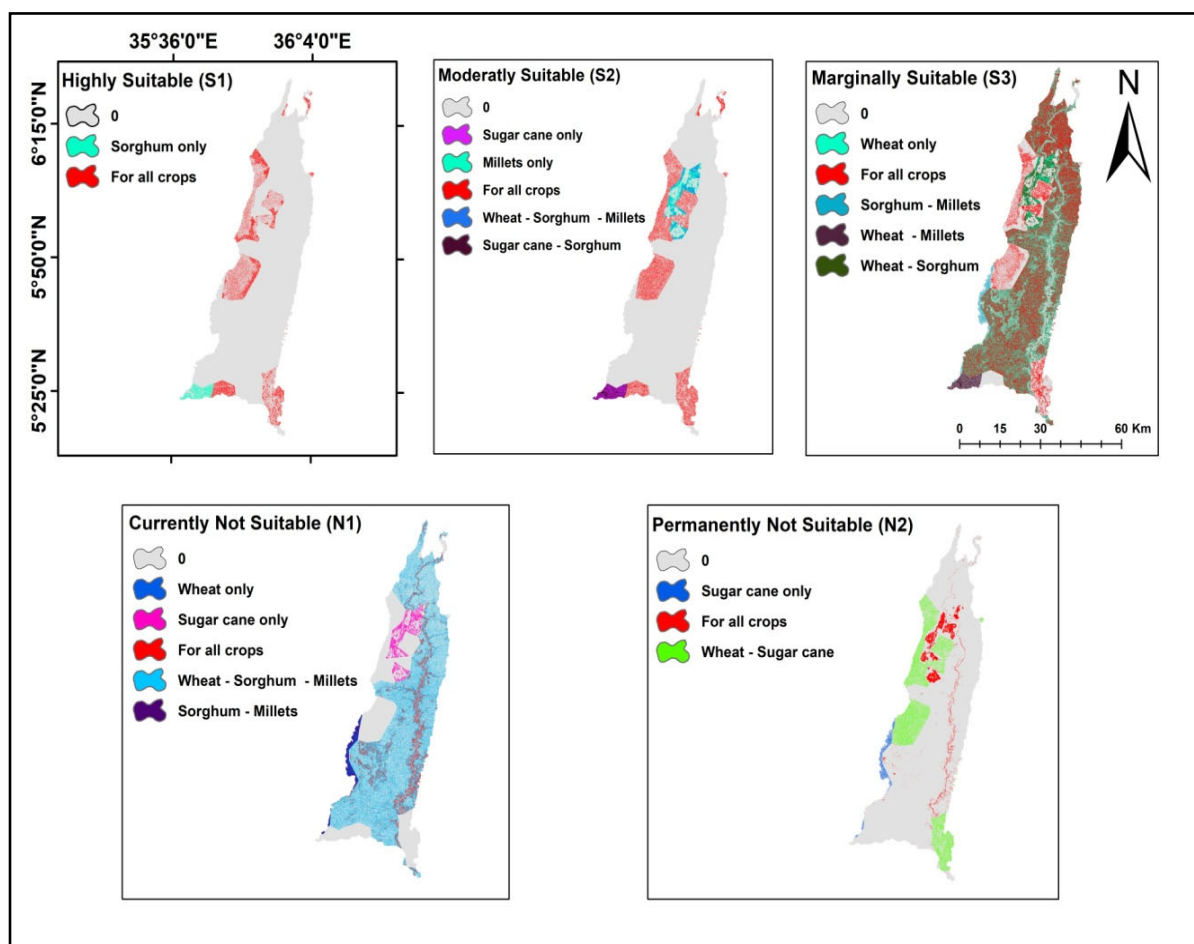


Figure 7. The land series codes corresponding to crop and suitability class.

The scientific approach to evaluating land suitability can play an indispensable role in boosting irrigated cropland and crop production for a specific area by considering different influencing factors [34]. This research will be useful in evaluating and assessing the potential crop yield of the study area and soil and climate degradation of cultivated lands in the lower Omo basin in southern Ethiopia. Integrated, the parametric method with a GIS environment has been widely used to assess land suitability [14–17]. Furthermore,

El-Aziz [35] determined that a parametric approach was used to determine the suitability of specific areas for a wide range of crops by evaluating the actual soil parameters.

4. Conclusions

Land suitability evaluation is vital for the sustainable development of the regions with effective management and utilization of the land resource. Accurate assessment methods give better results and allow for the establishment of improved management plans. Based on a parametric land suitability evaluation system, this study evaluated the suitability of surface irrigation-based production of millet, sorghum, sugarcane, and wheat on a 2530 km² area of land in the lower Omo Gibe basin in Southern Ethiopia. Soil texture, effective soil depth, Calcium carbonate (CaCO₃), the electrical conductivity of soil solution (ECE), drainage, and slope were recognized as factors affecting land suitability for production of the selected crops in the study area.

Due to steep slopes and shallow soil depth, sorghum and millets are classified as permanently unsuitable in land series 9 and 11. Poor soil drainage and steep slopes affect land series 19, 20, and 21 in the studied area. These land series are also designated as permanently unsuitable for wheat cultivation. The study results showed that land series coded 1, 2, 5, and 12 (167.1 km², 6.6%) have high suitability for all studied crops, and land series coded 14 and 15 (21.83 km², 0.9%) are highly suitable for only sorghum. The land series coded 9 and 21 (86.9 km², 3.4%) are permanently unsuitable for all studied crops. And land series coded 10 (17.6 km², 0.7%) is permanently unsuitable for all crops, in addition to land series coded 9, 11 and 21 (110.0 km², 4.4%) are permanently unsuitable for wheat and sugarcane.

Many options can be raised for the sustainable use of the land for crop production in the study area. Most importantly identification of the suitable land for specific crop will increase the agricultural productivity. For illustration, irrigating the crops in their specific suitable land series; amending some of the limiting factors such as pH through the application of fertilizers can lower the alkalinity effect in the soil (e.g., In land series coded 14, 15, and 16 in case of cultivating wheat); application of soil and water conservation measures to increase soil depth (e.g., Land series coded 7, 8, 9, 10 and 11 in case of cultivating sugarcane); and changing the land use type (e.g., land series coded 4, 9, 20 and 21 in case of cultivating sorghum) to other use types such as forest land because these land 'series' are located in such a steep area not suitable to irrigate. The study gives an insight into which type of crop included in this study (i.e., millet, sorghum, sugarcane, and wheat) is more feasible in which part of the basin and thus enhances decision-making processes. The use of geospatial data and techniques can be applied for increasing agricultural productivity by selecting a suitable crop for each land category.

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