ORIGINAL ARTICLE

Assessment of land suitability for irrigation in West Shewa zone, Oromia, Ethiopia

Abera Misgana Tolera[1] · Mesfin Mamo Haile[1] · Tadesse Fufa Merga[1] · Gemta Abdisa Feyisa[1]

Abstract

The assessment of land suitability is the key to sustained agricultural output. Thus, the study aimed to assess the land suitability for irrigation development in the West Shewa zone, Oromia, Ethiopia. A GIS-based analytical hierarchy process was applied to evaluate a multi-criteria land suitability analysis. The key factors such as soil (depth, drainage, texture, pH, organic carbon, available water content, and salinity), slope, land use/cover, proximity to the river, proximity to the road, proximity to urban areas, and rainfall deficit were considered. These factors were reclassified, weighted, and then overlaid using the weighted overlay tool of ArcGIS software. The study classified the agricultural lands in the area from highly suitable to permanently unsuitable for irrigation to determine the suitability of the classes. The results showed that 10.27% (1419.87 km²) was highly suitable, 73.23% (10,128.97 km²) was moderately suitable, 16.34% (2259.95 km²) was marginally suitable, and 0.16% (22.16 km²) was not suitable. The area in all woredas was mainly moderately suitable for irrigation. However, Metarobi had the most highly suitable land, followed by Elfata with the most moderately suitable land, and Abuna Gindeberet with the most marginally suitable land. The results revealed huge potential for irrigation development in the West Shewa zone. As a result, it can serve as the basis for zonal-level planning and future irrigation development. Therefore, the study helps to improve the community's lifestyle in the study area by increasing agricultural production.

Keywords Land suitability · Geographic information system · Weighted overlay · Multi-criteria analysis · Analytical hierarchy process

Introduction

Irrigation is the principal strategy for raising agricultural production. The public's understanding of irrigated agriculture has grown in Ethiopia. However, rain-fed agriculture, which is impacted by variable rainfall amounts and patterns, is the mainstay of the country's agricultural economy. Most of the population lives in highland areas, with 85% of the country's rural residents reliant on agriculture with low productivity levels. However, land resources are suitable for irrigation in the highlands of the country. Increasing agricultural production through irrigation is one of the key methods for providing farmers with a reliable source of income, raising their general well-being, and ending poverty. Despite its underutilization, only 4–5% of the country's irrigable land has been developed for irrigation. Furthermore, agriculture is suitable for 66% of the country's (roughly 74 million hectares). On the other hand, the country has 12 river basins with an estimated 2.6–6.5 billion m³ of potential groundwater and an annual runoff volume of 122 billion m³ (Awulachew et al. 2007; Worqlul et al. 2015; Nigussie et al. 2019; Balew et al. 2021).

Spatial information about land suitability for irrigation is critical to improving evaluation and decision-making on investments for irrigated agricultural development. Suitability assessments provide crucial information about suitability and limiting factors, which can help decision makers make the optimal use of valuable resources (Kiran et al. 2020). Land suitability assessments can serve as a foundation for future updates regarding irrigation development. Studies on irrigation suitability differ depending on the geographic extent, objectives, and criteria considered, as well as data accessibility. Numerous studies on irrigation suitability have been carried out at the national, basin, subbasin, and watershed scales, using various criteria. Despite several studies

✉ Mesfin Mamo Haile
  mesfinmamo0355@gmail.com

[1] Department of Hydraulic and Water Resources Engineering, Ambo University, Ambo, Ethiopia

being carried out across the country, little research has been done on land and irrigation suitability in this area.

Agriculture in Ethiopia is mainly rain fed, which is both temporally and spatially variable. The country has experienced a drought, and agricultural productivity is declining due to the highly erratic rainfall, expanding population, water scarcity, and land degradation. Land evaluation is the process of predicting land performance over time according to the specific types of use. Sustaining the productivity of the land becomes increasingly crucial as human demands increase. Evaluation of land suitability can contribute to better land management by reducing land degradation and establishing land use patterns that avoid environmental issues by separating competing land uses. Suitability analysis enables decision makers to develop crop management practices capable of increasing land productivity by identifying the main limiting factors for agricultural production (Mazahreh et al. 2019). The study area's economy, like other parts of Ethiopia, is heavily dependent on agricultural production. However, the overall crop yield is seen as quite poor. Despite having plenty of land and water resources, the West Shewa zone's agricultural system is not yet at its optimal production. In the West Shewa zone, rain-fed agriculture is the principal source of farm output and is only done once a year. Therefore, agricultural production is declining, and the community's standard of living is subsistence (Bekele 2008). On the other hand, not all perennial rivers in the West Shewa zone have been used for irrigation. Different evaluation techniques have been applied to the assessment of land suitability. However, GIS-based multi-criteria evaluation methods are widely used, effective at handling many criteria, and incorporate several elements to create a single indexed output. The AHP method was employed to rank alternatives, analyze several factors, and make decisions based on the MCE model. It is widely used in the study of water resources (Balew et al. 2021; Haile 2022; Mesfin Mamo Haile 2022; Haile et al. 2022; Rikitu et al. 2019). Therefore, the study evaluates the suitable land for irrigation in West Shewa zone, Oromia, Ethiopia.

Methodology

Description of the study area

West Shewa zone is one of the administrative zones of Oromia Regional State. It is located in the west of central Oromia, 114 km from Addis Ababa. It is bordered on the south by the Southwest Shewa zone and the Southern Nations, Nationalities, and Peoples Region; on the southwest by Jimma; on the west by East Wellega; on the northwest by Horo Guduru Wellega; on the north by the Amhara Region; on the northeast by North Shewa; and on the east by the Oromia Special zone surrounding Addis Ababa. It is at 8°17–8°57 N latitude and 37°08–38°07 E longitude, with an elevation of 1050–3500 m.a.s.l. Ambo is the administrative center of the zone. Its highest elevation is at Mt. Wanchi (3386 m above sea level); other notable peaks include Mt. Menagesha and Mt. Wachacha. It has annual average rain fall of 1,115 mm. The mean maximum and minimum temperatures are 25.4 and 11.7°C, respectively. The Dega, Woina-Dega, and Kolla agro-ecological zones cover 27, 56, and 17% of the total area of the zone, respectively. The term "highland" refers to areas above 2300 m above sea level, "midland" to areas between 1500 and 2300 m, and "lowland" to areas below 1500 m. The zone has a population of 2,327,845, of whom 290,282 (12.47%) are living in towns and 2,037,563 (87.53%) are living in rural area, which are highly dependent on agriculture. The total land area of this zone is 1,434,929 ha, which accounts for about 4.15% of the Oromia region's total land area. Land uses in the locality included cultivation, grazing, and forest with areas of 880,211 ha (61.34%), 249,645 ha (17.39%), and 104,799 ha (7.3%), respectively. In terms of topography, it has flat land (47.7%), up-down (25.7%), mountains (16.8%), valleys (4.6%), and others (5.2%). Corresponding to the variation in the landscape and other soil-forming factors such as climate and vegetation, the soil of the study area is also highly variable. A large portion of West Shewa is covered with vertisols, nitisols, luvisols, and leptosols (Rikitu et al. 2019; Assefa et al. 2018). Geographical location of the West Shewa zone is shown in Fig. 1.

Data collection

Land suitability assessment data on soil, slope, land use/cover, river, road, urban, rainfall, and evapotranspiration were collected from governmental agencies and online sources. These input data were used to generate criteria layers, which were then used to create a land suitability map (Table 1).

Factors and procedures of land suitability for irrigation

Irrigation has contributed significantly to the rural population's livelihoods, food security, and alleviating poverty (Hussien et al. 2019; Worqlul et al. 2017). The analytical procedures for land suitability for irrigation are explained by the flowchart diagram shown in Fig. 2. Factors
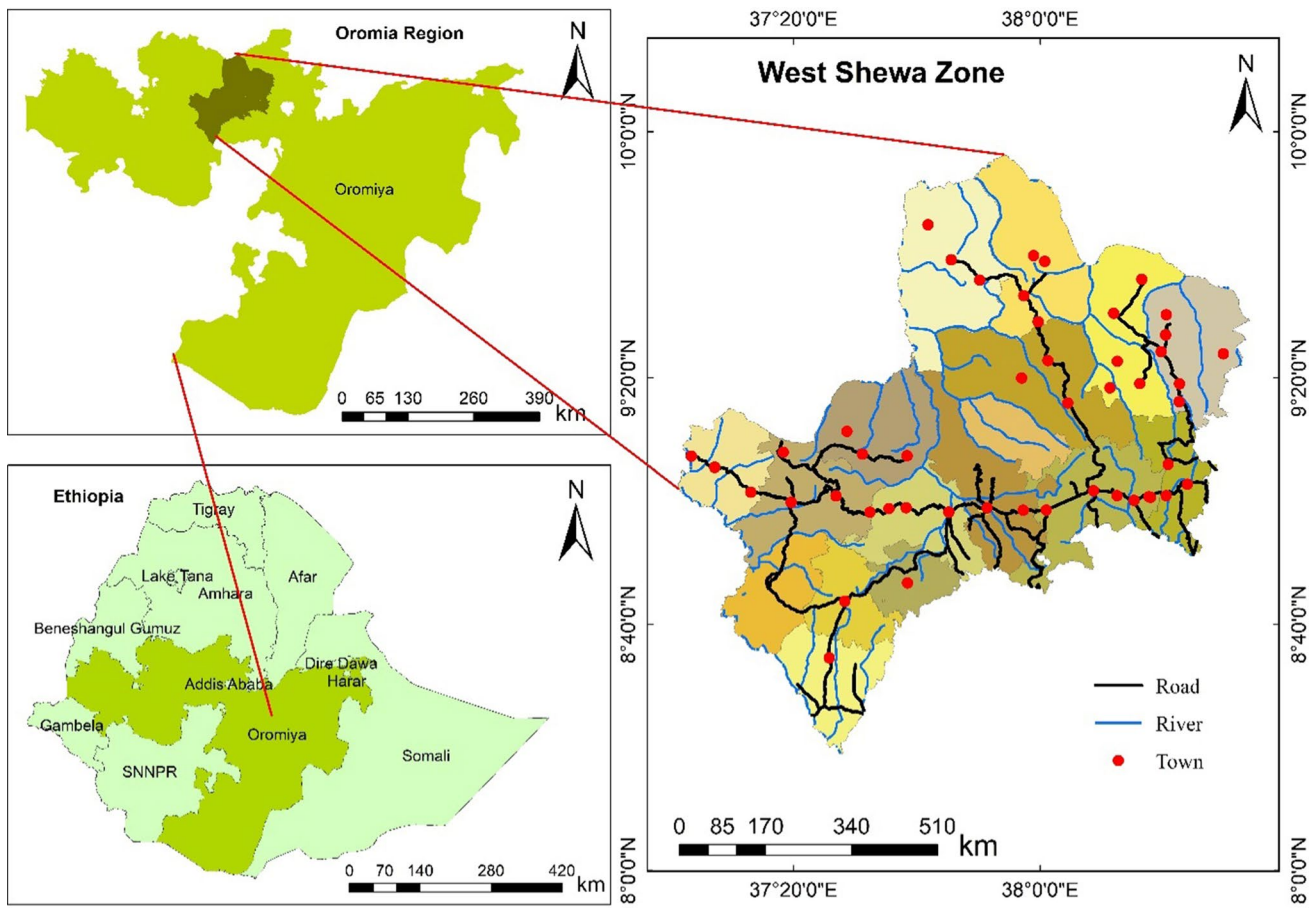
Fig. 1 Location map of West Shewa zone, Oromia, Ethiopia

Table 1 Data and their sources

Data	Source
SRTM digital elevation model	USGS website (https://earthexplorer.usgs.gov/)
Soil properties except for soil depth	Harmonized World Soil Database, version 1.2
Soil depth	AfSoilGrids250m
Land use/cover	European Space Agency Sentinel-2 Imagery
River network	Ministry of Water and Energy
Road network and urban areas	Ethiopian Online Map Sources
Rainfall	National Meteorological Agency
MODIS potential evaporation	MOD16 Global Terrestrial Evapotranspiration Dataset

determining land suitability for irrigation development were identified based on the literature, data availability, and expert opinion (Worqlul et al. 2019, 2017; Hussien et al. 2019; Kiran et al. 2020; Balew et al. 2021; Haile and Abebe 2022; FAO 1976). Slope, soil (soil depth, drainage, pH, texture, organic carbon, AWC, and salinity), land use/cover, distance from the rivers, the roads, and the towns,

and rainfall deficit were all considered and used as inputs to select the most suitable area for irrigation. Each input factor is reclassified to suitability classes based on the FAO proposed suitability scale. The critical limits used to define the factors' suitability classes were obtained from the literature. The suitability layer developed for each
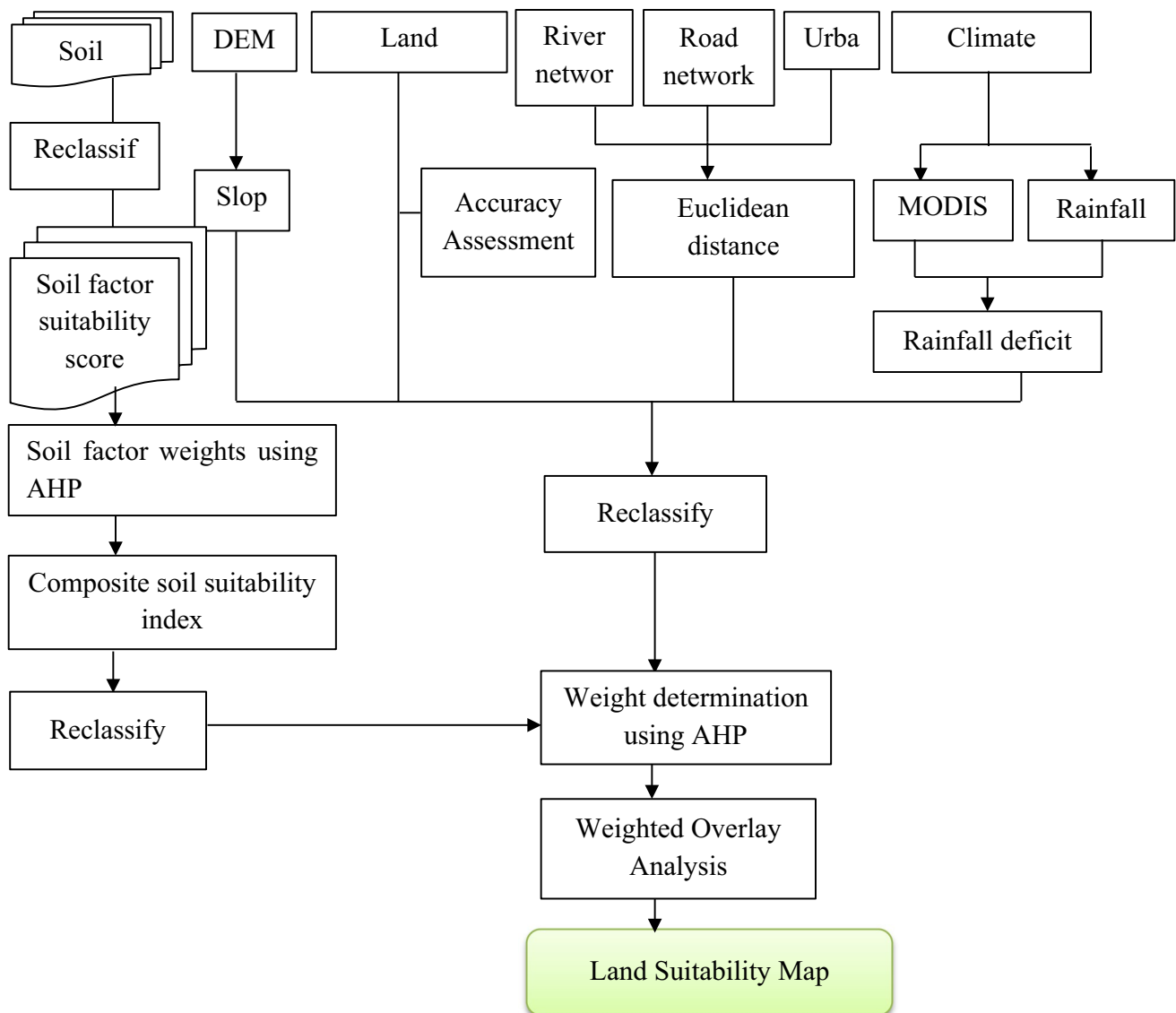
Fig. 2 Flow diagram method of land suitability for irrigation

Table 2 Land suitability classification (FAO, 1976)

Order	Suitability classes	Details
Suitable (S)	Highly suitable (S1)	Land having no substantial restrictions for specific land use activities
	Moderately suitable (S2)	Land with slight restrictions for specific land use activities
	Marginally suitable (S3)	Land with extreme restrictions for specific land use activities
Not Suitable (N)	Currently not suitable (N1)	Land with restrictions can be resolved in time rather than fixed with knowledge at a reasonable cost
	Permanently not suitable (N2)	Land which has severe restrictions that cannot be prevented using any possible solution

factor was aggregated to form the final land suitability for irrigation in the ArcGIS 10.4 software.

Classification of land suitability factors

Land suitability can be denoted as the fitness of a specific land use type for a given type of land. According to the FAO land suitability classification guideline, the land is predominantly classified into suitable (S) and not suitable (N) categories and further divided into different classes (DAS 2021; Congalton 2001). A standard framework for land suitability analysis for irrigation development, based on specific soil, land use/cover, water sources, and topographic data, with suitability classes ranging from highly suitable to unsuitable, was established using FAO (Table 2).

Slope

The suitability of an area for land preparation and irrigation operations is influenced by the slope of the land (FAO 1976). It also affects irrigation methods, land development, on-farm irrigation system design, erosion risk, drainage requirements, water use practices, crop output, and other management and production expenditures (Worqlul et al. 2017). The slope of the land was determined using a 30-m resolution digital elevation model (DEM). A 30 m × 30 m digital elevation model was used to calculate the percentage change in elevation over a given distance and further classified into different classes based on Kiran et al. (2020) slope classification: 0–5% as S1 (highly suitable), 5–8% as S2 (moderately suitable), 8–15% as S3 (marginally suitable), 15–30% as N1 (currently not suitable), and more than 30% as N2 (permanently not suitable).

Soil

Soil is a key determinant of land suitability for agriculture and long-term irrigation (Hussien et al. 2019; Worqlul et al. 2017). The physical and chemical properties of soil, such as drainage, texture, soil depth, available water storage capacity, pH, organic carbon, and salinity, were downloaded from the Harmonized World Soil Database (HWSD) version 1.2 and AfSoilGrids250m datasets and used to assess its suitability for irrigation. It was divided into five suitability classes (Kiran et al. 2020; Worqlul et al. 2017), as given in Table 5.

A GIS-based multi-criteria evaluation (MCE) procedure combined various factors to produce the pixel-wise composite soil suitability classification (Kiran et al. 2020). The analytical hierarchy process model of ArcGIS software extension derived the factor weights based on the relative importance of suitability factors. The weighted sum tool in ArcGIS generated a composite soil suitability index by applying the factor weights to the factor classes with suitability scores. The composite soil suitability index was divided into suitability classes as given in Table 3.

Land use/cover

Land use and land cover of the study area are among the most important factors for irrigation. A land use type is a land use described in terms of its products and management practices. Land use data help identify an area's productivity for irrigation (Hussien et al. 2019). The land use and land cover (LULC) was downloaded from European Satellite Agency Sentinel-2 imagery (https://livingatlas.arcgis.com/landcover/) at 10 m resolution and can be used to analyze land use/land cover suitability for irrigation. The classes of LULC are water, forests/trees, vegetation, crops, built areas, bare ground, and rangeland. Land suitability is the fitness of a given type of land for a defined use by the Food and Agricultural Organization (DAS 2021). According to DAS (2021), Worqlul et al. (2017), and Kiran et al. (2020), land use/cover is classified into five classes: highly suitable (S1), moderately suitable (S2), marginally suitable (S3), currently not suitable (N1), and permanently not suitable (N2). Crop area/agricultural land use types were classified as highly suitable and rangeland, which includes land preparation, as moderately suitable. Flooded vegetation and bare ground, which require a higher initial investment for land preparation, were marginally suitable. Forests/trees was classified as currently not suitable. Built-up areas and water were classified as permanently not suitable. A total of 450 random points were generated, and then, Google Earth was used to verify the classified image. Accuracy assessments such as overall accuracy and kappa coefficients were computed from the error matrix based on Congalton, Sarkar (2018), and Sarkar Saaty (1977).

Proximity to rivers

Proximity to the river network is an essential criterion for evaluating irrigable land from a surface water source. Agricultural lands near rivers and streams have easy access to

Table 3 Suitability classification of the composite soil index

Composite soil suitability index (%)	Suitability class	Suitability code
> 80	Highly suitable	S1
60–80	Moderately suitable	S2
45–60	Marginally suitable	S3
30–45	Currently not suitable	N1
< 30	Permanently not suitable	N2

water for crop production. Furthermore, the command area's proximity to water decreases the expense of canal development and water loss. Euclidean distances were determined from each river to identify irrigable land near rivers (Haile and Abebe 2022). The equal interval method was applied to classify the Euclidean distances from the rivers into 0–3 km as S1 (highly suitable), 3–6 km as S2 (moderately suitable), 6–9 km as S3 (marginally suitable), 9–12 km as N1 (currently not suitable), and greater than 12 km as N2 (permanently unsuitable).

Proximity to roads

Road accessibility is another parameter that indicates market access. It is used to increase market access and thereby increase agricultural production. Vector data for the West Shewa zone's asphalt and gravel road network were retrieved from online map sources for Ethiopia. The equal interval method was used to classify Euclidean distances from asphalt and gravel roads into 0–7 km as S1 (highly suitable), 7–14 km as S2 (moderately suitable), 14–21 km as S3 (marginally suitable), 21–28 km as N1 (currently not suitable), and greater than 28 km as N2 (permanently unsuitable).

Proximity to urban areas

Urban areas were extracted from online map sources for Ethiopia. It was used to compute Euclidean distances, determining how close towns are to agricultural land. The equal interval method was used to classify Euclidean distances from urban areas into 0–7 km as S1 (highly suitable), 7–14 km as S2 (moderately suitable), 14–21 km as S3 (marginally suitable), 21–28 km as N1 (currently not suitable), and greater than 28 km as N2 (permanently unsuitable).

Rainfall deficit

Rainfall and potential evapotranspiration are among the essential criteria for determining land suitability for irrigation. The monthly rainfall data for 18 years (2000–2018) were obtained from the Ethiopian National Meteorological Agency and were aggregated into an annual. The annual rainfall was interpolated using the inverse distance weighting (IDW) interpolation method to estimate the spatial distribution of rainfall in the West Shewa zone. The potential evapotranspiration for 20 years (2000–2020) at an 8-day time step with a 1×1 km resolution was collected using the MODIS global evapotranspiration (ET) products. The 8-day MODIS ET was aggregated to get the average annual potential evapotranspiration. The mean annual rainfall deficit was estimated by subtracting the mean annual potential evapotranspiration from the mean annual rainfall (Hussien et al. 2019). The equal interval method was used to classify the mean annual rainfall deficit into -1.2 to -0.8 mm as S1 (highly suitable), -0.8 to -0.4 mm as S2 (moderately suitable), -0.4 to 0 mm as S3 (marginally suitable), 0 to 0.4 mm as N1 (currently not suitable), and greater than 0.4 mm as N2 (permanently unsuitable).

Standardizing and weighting of factors

Each factor was transformed into a raster, and the reclassification spatial analyst tool was used to standardize the factors in an ArcGIS environment. The factors were reclassified and ranked based on the FAO framework's five classes of agricultural land suitability for irrigation. The importance of each factor relative to the other factor was determined by reviewing relevant literature and expert

Table 4 Saaty's pairwise scale and its explanation (Congalton 1991)

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective
3	Weak importance	Experience and judgment slightly favor one over the other
5	Strong importance	Experience and judgment strongly favor one over the other
7	Very strong importance	Experience and judgment very strongly favor one over the other. Its importance is demonstrated in practice
9	Extreme importance	The evidence favoring one over the other is of the highest possibility of validity
2, 4, 6, and 8	Intermediate values	When compromise is needed

judgment to complete a pairwise comparison matrix in the analytical hierarchy process of ArcGIS 10.4 software extension. The following numbers are available for comparison: 9, 7, 5, 3, 1, 1/3, 1/5, 1/7, and 1/9, with 9 signifying absolute importance and 1/9 representing absolute triviality (Saaty, 1977) (Table 4). The final weights of all factors were derived using an analytical hierarchy process model (AHP 2.0). The factor weights were then examined to conduct a multi-criteria assessment of irrigation suitability (Worqlul et al. 2017).

Weighted overlay analysis

All factors were projected into WGS 1984 UTM Zone 37N to achieve the same geographic extent and resampled to 30 m resolution. The discrete data such as land use/cover, soil, roads, rivers, and urban areas were resampled using the nearest-neighbor method, and the continuous data such as slope and rainfall were resampled by using the bilinear method. Reclassified and weighted factors are overlaid to select the most suitable irrigable area. The weighted overlay analysis of the spatial analyst tool combined all factors for multi-criteria evaluation after the weights were generated using the AHP tool. Finally, a map of land suitability for irrigation is created.

Results and discussion

Factors suitability

The results of the selected factors such as soil, slope, land use/cover, proximity to rivers, roads, and urban areas, and rainfall deficit are presented and discussed.

Soil factors such as drainage, depth, texture, pH, organic carbon, available water storage capacity, and salinity were assessed to determine whether they were suitable or not for irrigation development. The soil drainage of the area was classified as 63.39% moderately well drained, 34.85% poorly drained, and 1.76% very poorly and excessively drained. The soil depth of the area was 98.62% in the range
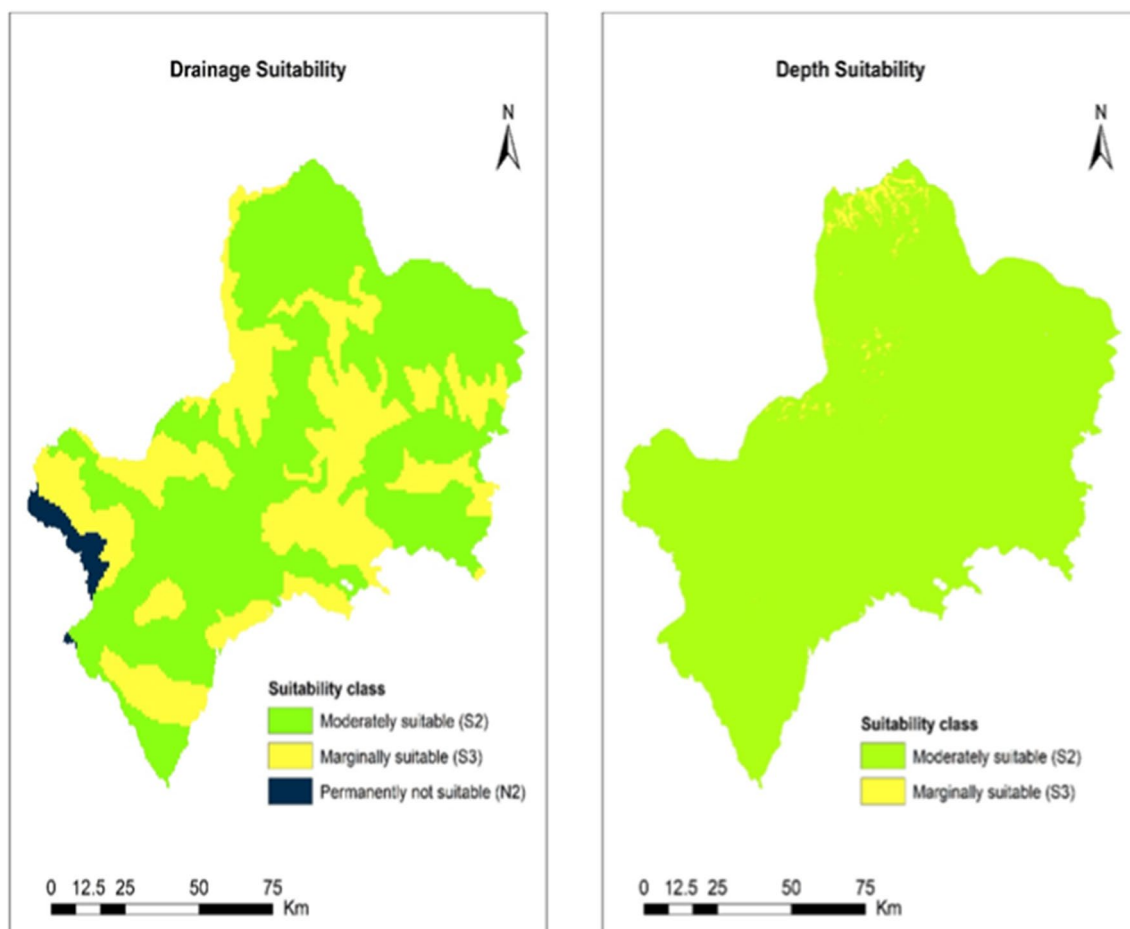

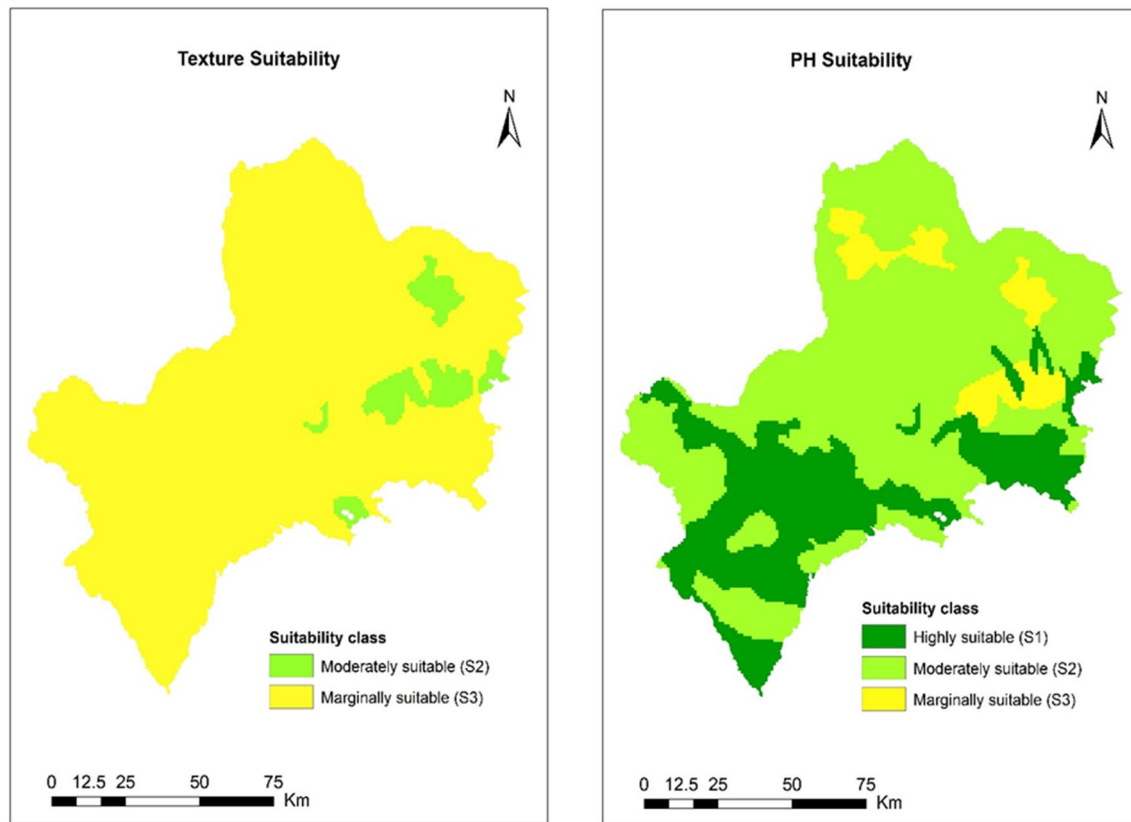**Fig. 3** Soil drainage and soil depth suitability map

Fig. 4 Soil texture and soil pH suitability map

of 120–200 cm, which is moderately suitable, and 1.38% in the range of 60–120 cm, which is marginally suitable. The soil drainage and soil depth are shown in Fig. 3.

As shown in Fig. 4, the soil texture of the area was 94.36% marginally suitable, which is light clay, sandy clay loam, and sandy loam. About 5.64% of the area was moderately suitable, which is silty clay loam, sandy clay, and loam. The pH of the area was 64.33% in the range of 6.6–7.3, which is moderately suitable, and 28.45% in the range of 5.5–6.6, which is the best pH condition for nutrient availability and suitable for most crops. The remaining 7.22% is in the range of very acidic soils (4–5.5) and carbonate rich soils (7.3–8.5), which are marginally suitable.

Organic carbon also indicates the health status of the soil. As shown in Fig. 5, 7.22% of the area had more than 2% of organic content, which is fertile soil with a good structure; 39.39% of the area had 0.6–1.2% of organic content, which needs organic or inorganic fertilizer application to be productive; and 53.39% of the area was in the range of 0.2–0.6%, which is currently not suitable. 65.15% of the soil

in the area contains available water storage capacity of more than 150 mm per meter depth of the root zone; 9.18% of the soil was in the range of 100–125 mm/m, which is marginally suitable; and 25.67% was in the range of 15–50 mm/m, which is permanently not suitable.

The salt content of soil was roughly estimated from the electrical conductivity of the soil. 73.05% of the soil in the area had an electrical conductivity of less than 0.1 ds/m, which was classified as highly suitable, and 26.95% was in the range of 0.1–1.1 ds/m, which is moderately suitable (Fig. 6).

The results of soil factors are given in Tables 5 and 6. It was almost moderately and marginally suitable for drainage, depth, and texture. However, it was highly suitable for pH, organic carbon, available water content, and salinity. Moreover, the major portion of available water content and salinity is highly suitable. Only 2% of drainage and 27% of available water content are unsuitable for irrigation. In addition, about 53% of organic carbon is unsuitable for irrigation.
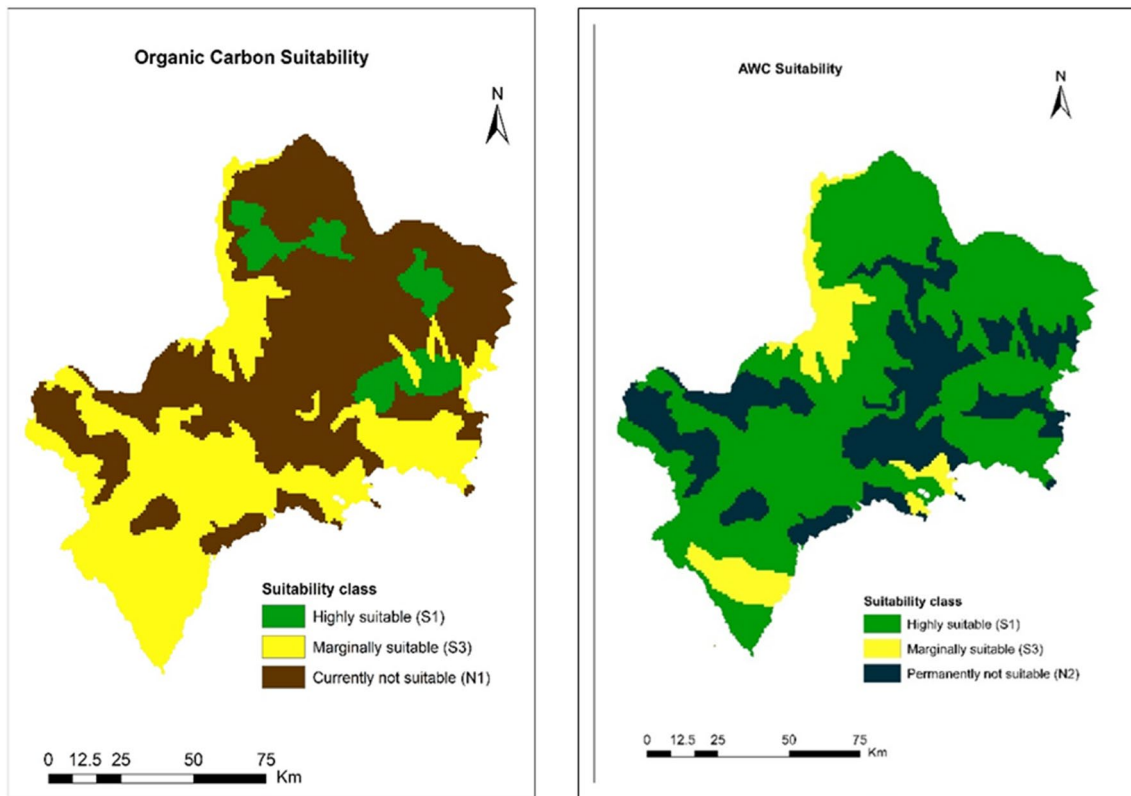
Fig. 5 Organic carbon and AWC suitability map

The slope is a crucial consideration when determining whether or not a piece of land is suitable for irrigation. The slope results indicated that 16.76% of the area has 0–5% slope, which is highly suitable; 11.93% of the area has 5–8% slope, which is moderately suitable; 24.98% of the area has 8–15% slope, which is marginally suitable; 31.62% of the area has 15–30% slope, which is currently not suitable; and 16.71% of the area has more than 30% slope, which is permanently not suitable. From slope results, more than 50% of the West Shewa land is suitable for irrigation development (Fig. 7).

Understanding the land surface information and the purpose for which it is used requires knowledge of land use and land cover. The findings indicated that 65.93% of land use/cover was cultivated area or agricultural land (highly suitable), 16.37% was rangeland (moderately suitable), 0.10% was flooded vegetation and bare ground (marginally suitable), 13.02% was forests and trees (currently not suitable), and 4.59% was built-up areas and water bodies (permanently not suitable). Around 82% of the area is suitable, whereas the remaining 18% is not. Land use/cover is shown in Fig. 8. The land use land cover classification accuracy assessments revealed that the overall accuracy is 84.64% and the kappa coefficient is 0.823. The accuracy assessment results are acceptable (Sarkar 2018; Mideksa and Temesgen 2020).

Irrigated agriculture relies on water supply to achieve optimal plant growth. The river's proximity to the command area was 55.48% at a distance of 0–3 km (highly suitable), 33.06% at a distance of 3–6 km (moderately suitable), 9.74% at a distance of 6–9 km (marginally suitable), 1.6% at a distance of 9–12 km (currently not suitable), and 0.15% at a distance of more than 12 km (permanently not suitable) (Fig. 9).

The land suitability for irrigation in terms of proximity to market outlets like roads and towns was assessed to identify whether the harvested products were accessible to the market. Infrastructure accessibility facilitates the production's timely arrival at market outlets without any destruction and further expenditure. Based on the assessment, 61.41 and 40.96% of the area were at a distance of
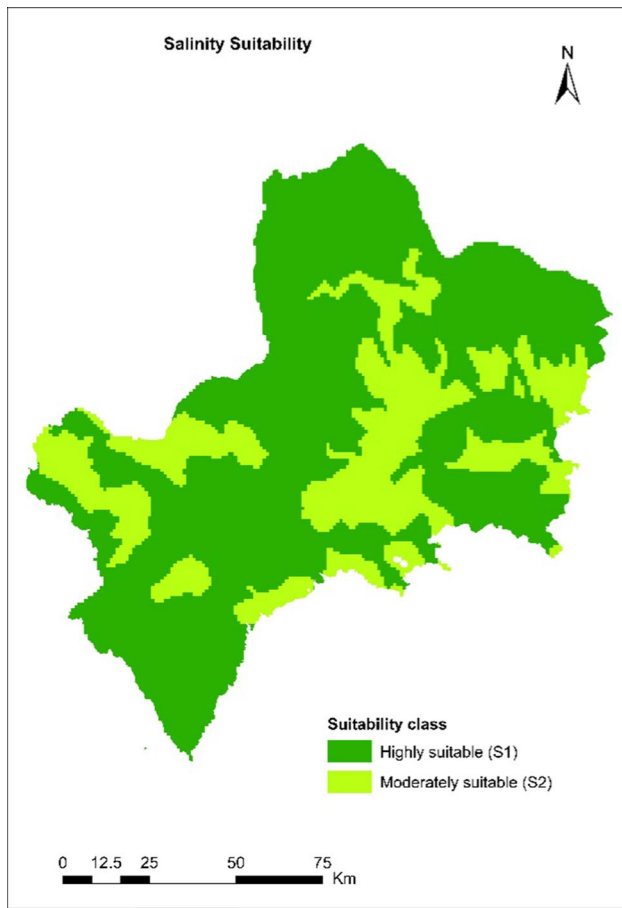
Fig. 6 Salinity suitability map

0–7 km (highly suitable), 25.23 and 39.65% at a distance of 7–14 km (moderately suitable), 9.33 and 14.70% at a distance of 14–21 km (marginally suitable), 3.68 and 4.11% at a distance of 21–28 km (currently not suitable), and 0.35 and 0.58% at a distance of more than 28 km (permanently unsuitable), respectively, for roads and towns. Generally, the major portion of the study area is accessible to the market outlets and suitable for irrigation development. Suitability maps of the road and the town's proximity are shown in Figs. 10 and 11, respectively.

The rainfall deficit was calculated by subtracting monthly evapotranspiration from monthly rainfall and interpolated over the West Shewa zone using inverse distance weighting. The results indicated that rainfall deficit was 77.60% in the range of −1.2 to −0.8 mm (highly suitable), 17.80% in the range of −0.8 to −0.4 mm (moderately suitable), 1.36% in the range of −0.4 to 0 mm (marginally suitable), 1.36% in the range of 0 to 0.4 mm (currently unsuitable), and 1.86% more than 0.4 mm (permanently unsuitable) (Fig. 12). It revealed the need for irrigation in the area for

Table 5 Soil factors and their suitability classes

Soil factors class	Suitability class
Drainage class	
Moderately well drained	Moderately suitable
Imperfectly drained and poorly drained	Marginally suitable
Very poorly drained and	Not suitable
Somewhat excessively drained	
Texture class	
Clay loam, silt loam	Highly suitable
Silty clay loam, sandy clay, loam	Moderately suitable
Clay (light), sandy clay loam, and sandy	Marginally suitable
loam	Currently not suitable
Loamy sand	Not suitable
Clay (heavy), sand	
AWC (mm/m)	
> 150	Highly suitable
125–150	Moderately suitable
100–125	Marginally suitable
50–100	Currently not suitable
15–50	Not suitable
Depth to bedrock (cm)	
120–200	Moderately suitable
60–120	Marginally suitable
30–60	Currently not suitable
< 30	Not suitable
pH class	
5.5–7.3	Highly suitable
4–5.5 and 7.3–8.5	Marginally suitable
< 4 and > 8.5	Currently not suitable
Organic carbon (%)	
> 2.0	Highly suitable
1.2–2.0	Moderately suitable
0.6–1.2	Marginally suitable
0.2–0.6	Currently not suitable
< 0.2	Not suitable
Electrical conductivity, ds m^{-1}	
< 0.1	Highly suitable
0.1–1.1	Moderately suitable
> 1.1	Not suitable

crop production. Key factors that significantly affect irrigation land suitability are summarized in Table 7.

Weight calculation

Based on reviewed literature and expert consultation, the factors were weighted relative to their importance (Liu et al. 2017). The weights of the factors were calculated using the AHP 2.0 tool of the ArcGIS extension. The weight of each soil factor was first determined and finally integrated to form soil factor suitability. Soil factor suitability was considered as one element in the determination of the final suitability. As seen from Table 8, the derived weight is maximum for drainage and minimum for salinity. It indicates that salinity,

Table 6 The results of soil factors

S/N	Soil factors	Suitability	Area (km²)	(%)
1	Drainage	S2	8819.30	63.39
		S3	4847.88	34.85
		N2	244.81	1.78
2	Depth	S2	13,698.59	98.62
		S3	191.06	1.38
3	Texture	S2	784.11	5.64
		S3	13,127.88	94.36
4	PH	S1	3958.70	28.45
		S2	8949.14	64.33
		S3	1004.14	7.22
5	Organic Carbon	S1	1004.14	7.22
		S3	5480.39	39.39
		N1	7427.45	53.39
6	AWC	S1	9064.11	65.15
		S3	1276.88	9.18
		N2	3571.00	25.67
7	Salinity	S1	10,162.02	73.05
		S2	3749.97	26.95

or the amounts of salt in the soil, is managed with adequate drainage.

The soil factors' consistency ratio estimated using AHP was 0.054, which is found worthwhile (Hagos et al. 2022). The weighted sum was calculated in ArcGIS software using the soil factor derived weights and suitability scoring factors to generate the composite soil suitability index. The obtained composite soil suitability index value ranges from 51 to 83%. It was classified as 5.64% highly suitable, 66.91% moderately suitable, and 27.44% marginally suitable. The generated composite soil suitability categories are shown in Fig. 13.

The final weights were calculated, and the results are listed in Table 9. The composite soil factor suitability was considered as one element in the determination of the final weights. The overall consistency ratio was estimated to be 0.064, which is found to be acceptable (Hagos et al. 2022). The results of weight determined indicated that the proximity to the river was maximum and land use/land cover was minimum. It indicates that the river's proximity to the command area is more crucial for irrigated agriculture. It has a significant contribution to irrigation development, mainly in areas with a high rainfall deficit, and it prioritizes the area to be irrigated using the river. Even though all life depends on land, only productive land use or cover is necessary for irrigation development. The weight results of proximity to river and land use land cover are similar to Assefa et al. (Hussien et al. 2019) and Hagos et al.[26] in which they were maximum and minimum, respectively. The weight results of proximity to the rivers and land use land cover in this study
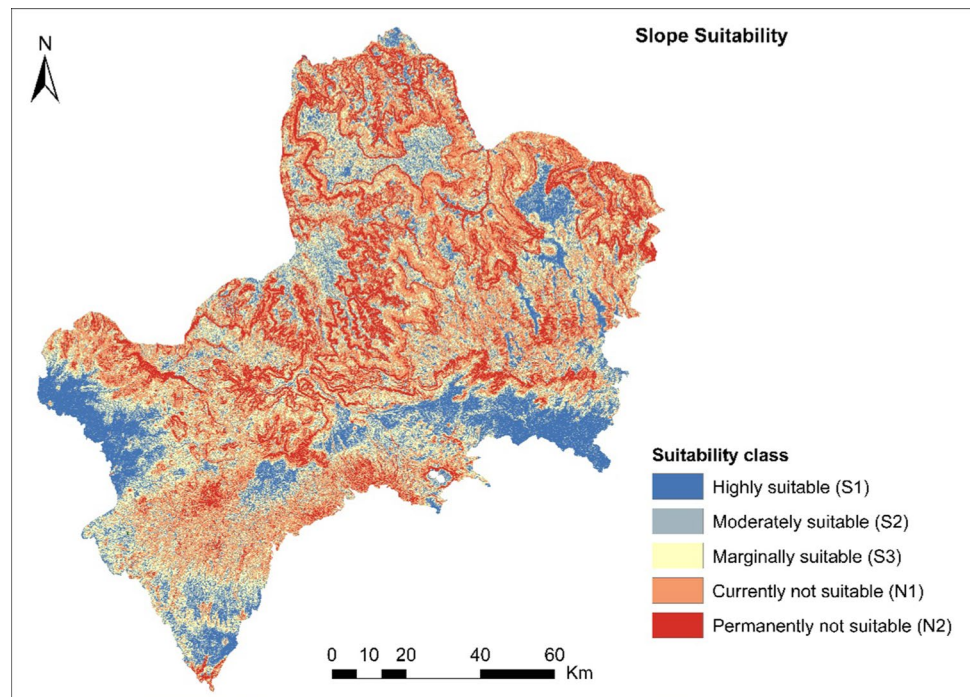
Fig. 7 Slope suitability map

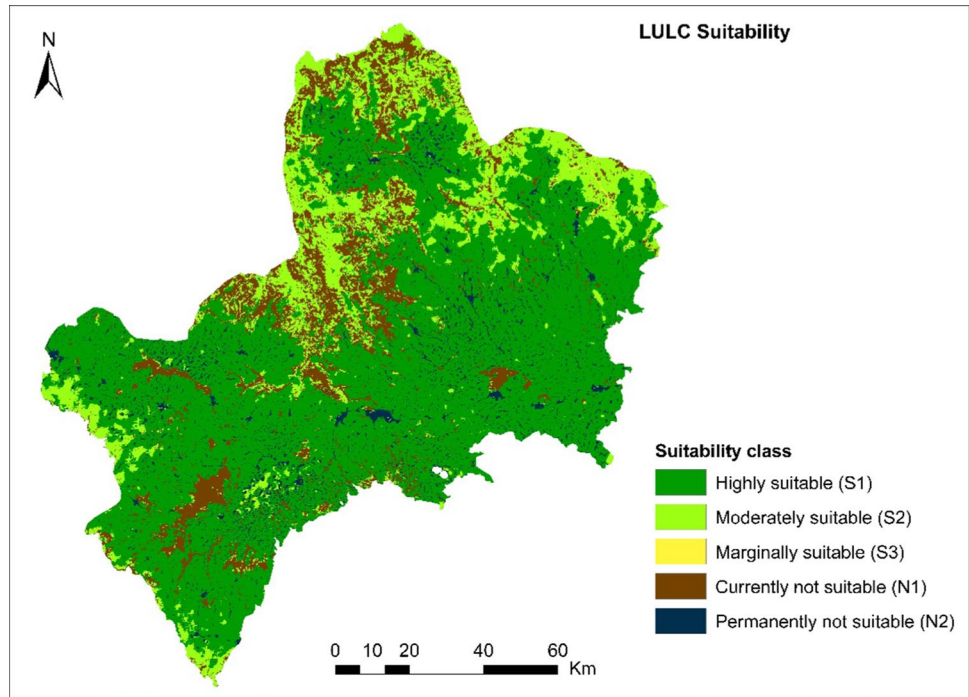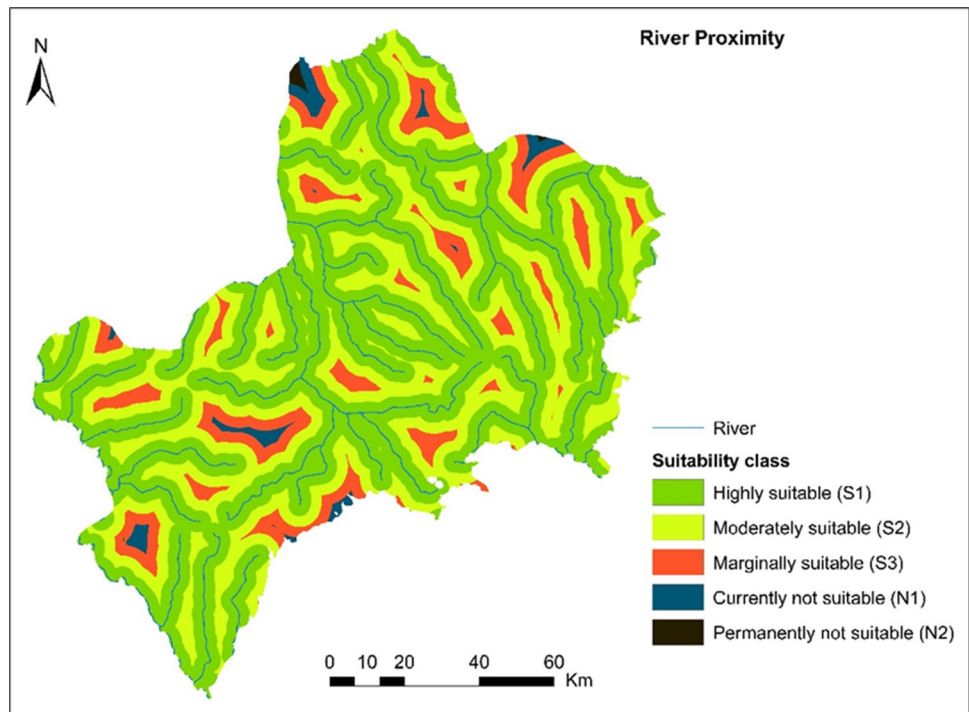**Fig. 8** Land use land cover suit-
ability map

Fig. 9 Proximity to river suit-
ability map

are similar to those of Assefa et al. (Hussien et al. 2019) and Hagos et al. [26].

Land suitability assessment for irrigation

The final land suitability for irrigation was estimated using the weighted overlay tool in ArcGIS 10.4 with suitability

scored factors, derived weights, and an evaluation scale. The land of the study area was classified as 10.27% (1419.87 km²) highly suitable, 73.23% (10,128.97 km²) moderately suitable, 16.34% (2259.95 km²) marginally suitable, and 0.16% (22.16 km²) currently not suitable (Fig. 14 and Table 10). Therefore, the majority of the land was suitable for irrigation development, while just a minor percentage

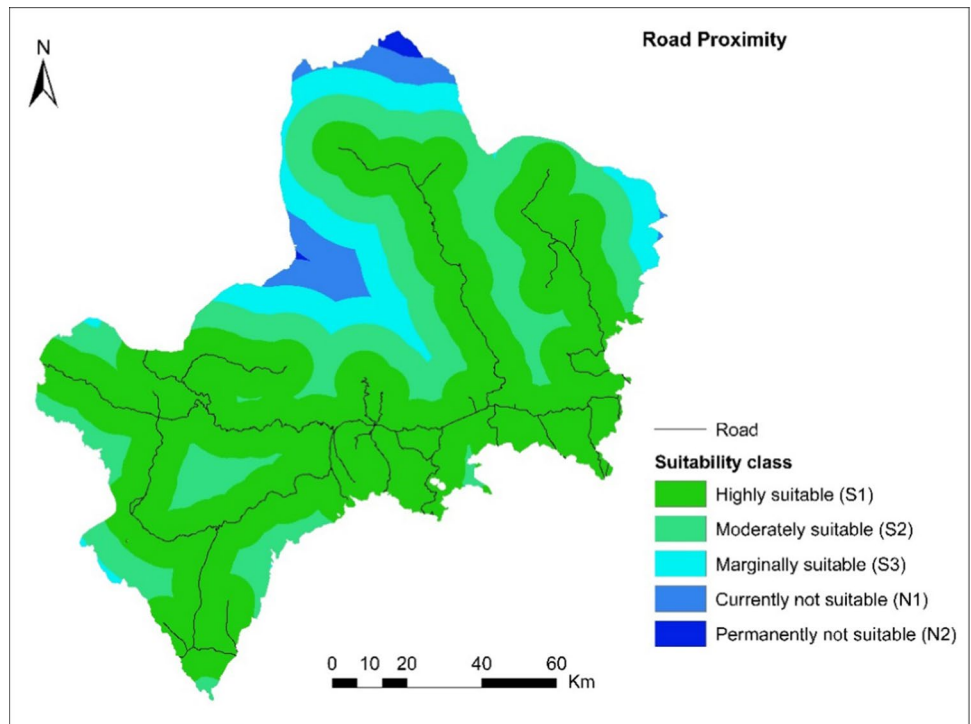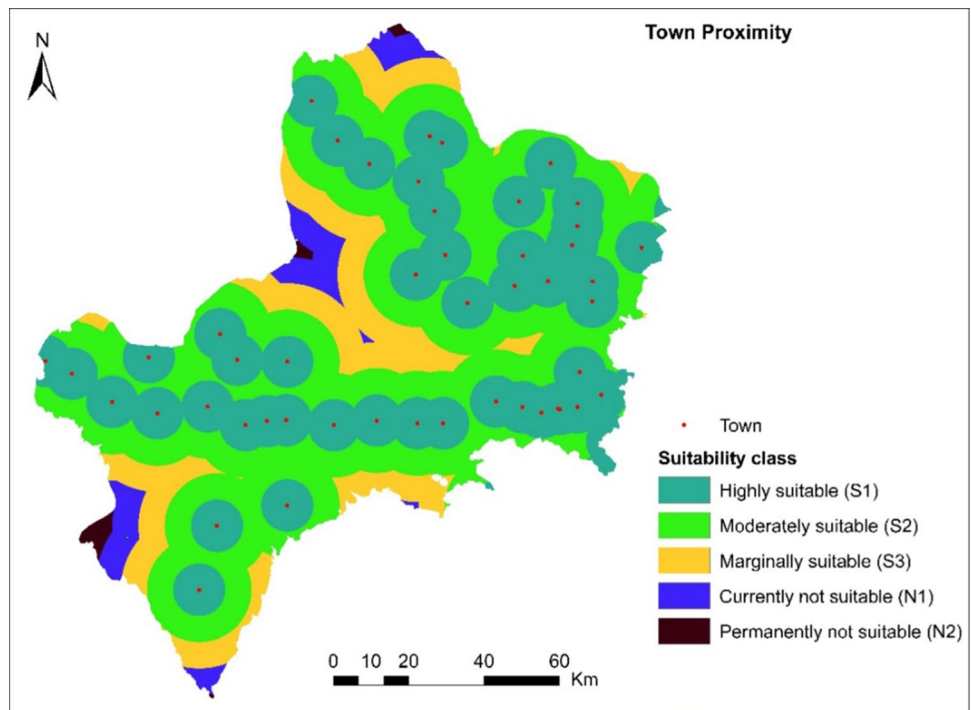**Fig. 10** Road proximity suitability map

Fig. 11 Town proximity suitability map

was unsuitable. The suitability of each woreda in the West Shewa zone was assessed, and the results are listed in Table 11. According to the findings, the amount of highly suitable land was maximal in Metarobi woreda, followed by moderately suitable land in Elfata woreda, marginally suitable land in Abuna Gindeberet, and currently unsuitable land in Gindeberet. Generally, the area in all woredas was mainly moderately suitable for irrigation.
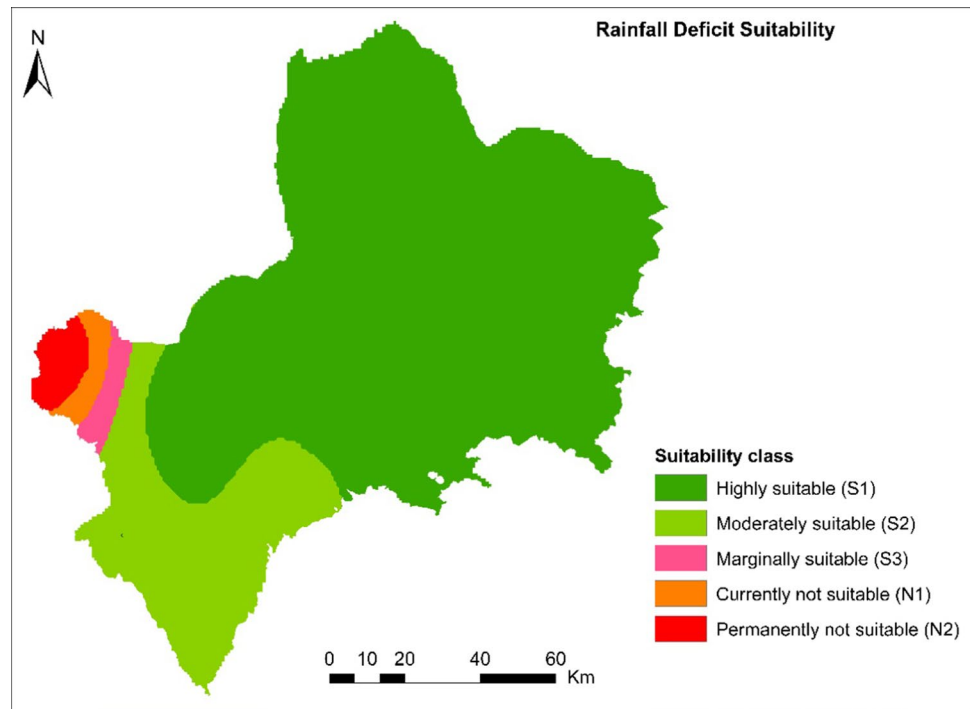
Fig. 12 Rainfall deficit suitability map

Table 7 The area and percentage of each factor's suitability class

S/N	Factors	Area per each suitability class (km^2)					Percentage per each suitability (%)				
		S1	S2	S3	N1	N2	S1	S2	S3	N1	N2
1	Soil factors	781.86	9269.05	3801.24			5.6	66.9	27.4		
2	Slope	2051.47	1658.91	3472.63	4394.81	2323.05	14.8	11.9	25	31.6	16.7
3	Land use land cover	9165.12	2276.17	13.11	1809.66	638.15	65.9	16.4	0.1	13.0	4.6
4	River proximity	7712.89	4595.40	1353.78	218.00	21.41	55.5	33.0	9.7	1.6	0.2
5	Road proximity	8536.91	3507.53	1296.36	511.35	49.33	61.4	25.2	9.3	3.7	0.4
6	Urban proximity	5693.81	5512.04	2042.95	571.43	81.24	41.0	39.7	14.7	4.1	0.6
7	Rainfall deficit	10,793.8	2476.02	189.84	190.46	258.66	77.6	17.8	1.4	1.4	1.8

Table 8 Results of the weight of soil factors

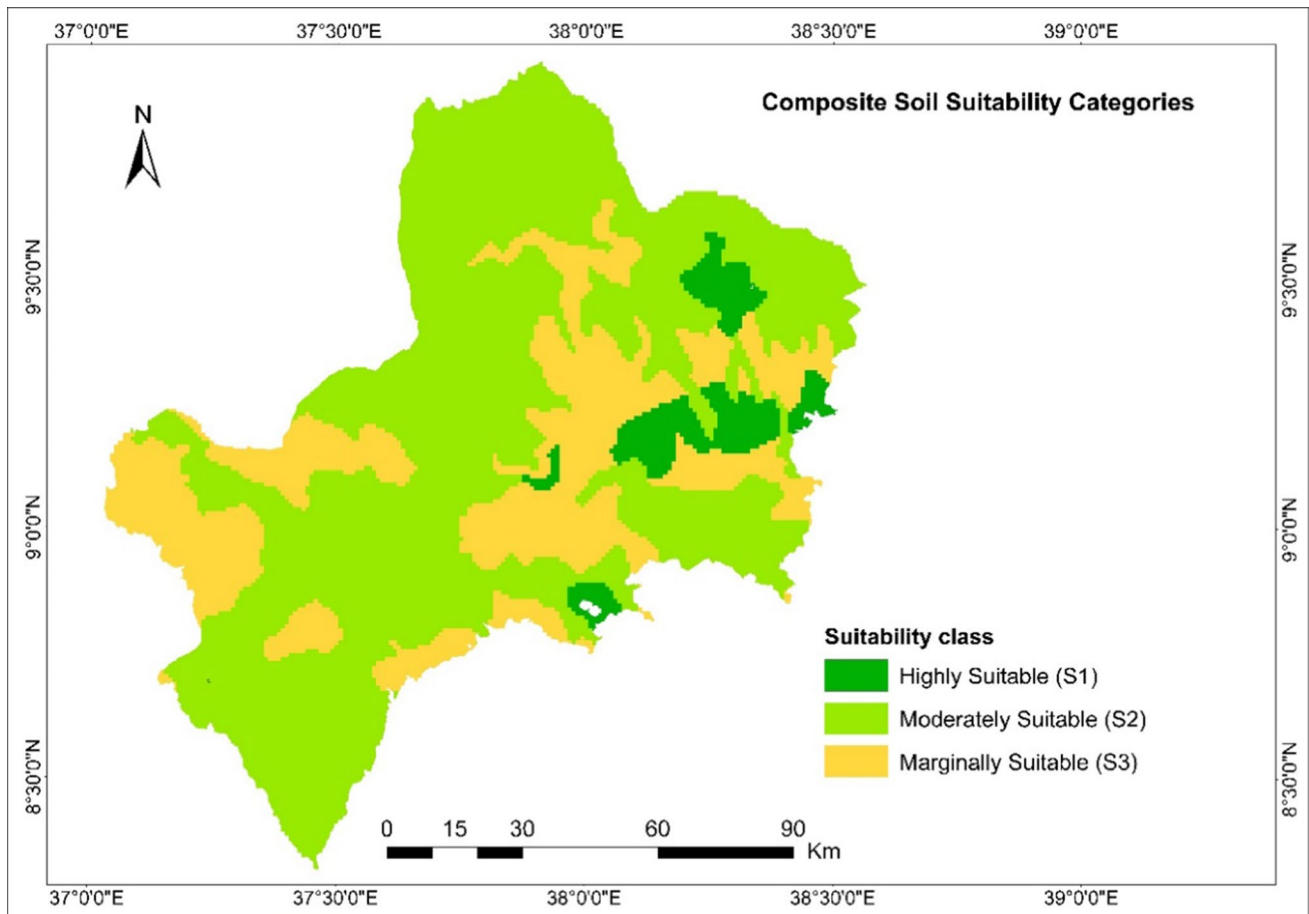| Factors	Depth	Drainage	Texture	PH	AWC	OC	Salinity	Weight (%)
Depth	1	1/4	1/4	2	1	2	5	11.34
Drainage	4	1	2	3	3	5	5	32.28
Texture	4	1/2	1	3	3	4	5	25.81
PH	1/2	1/3	1/3	1	1/3	2	4	8.50
AWC	1	1/3	1/3	3	1	2	4	12.69
OC	1/2	1/5	1/4	1/2	1/2	1	3	6.08
Salinity	1/5	1/5	1/5	1/4	1/4	1/3	1	3.30

Fig. 13 The categories of composite soil suitability map

Table 9 Land suitability factors' weights results

Factors	Soil	Slope	LULC	RiP	RoP	UP	RD	Weight
Soil factors	1	1/3	4	1/3	3	4	5	16.35
Slope	3	1	5	1/3	3	3	5	22.25
Land use Land cover (LULC)	1/4	1/5	1	1/7	1/3	1/2	1/3	3.32
River proximity (RiP)	3	3	7	1	5	5	9	38.75
Road proximity (RoP)	1/3	1/3	3	1/5	1	2	3	8.62
Urban proximity (UP)	1/4	1/3	2	1/5	1/2	1	3	6.55
Rainfall deficit (RD)	1/5	1/5	3	1/9	1/3	1/3	1	4.15

Comparison of the land suitability results with previous studies

The results of this study are more or less related to the following findings: Kiran et al. (2020) indicated that 66.4% of the 134 planned irrigation schemes' area in the Abay basin has a moderate suitability for irrigation. In this study, moderately suitable is also 73.23% of the study area. According

to a study by Worqlul et al. (2019) in Ethiopia, the Abay, Awash, Rift Valley, and Omo Gibe basins have significant potential for irrigation area. Therefore, the Abay, Awash, and Gibe basins are where the West Shewa zone is situated. Additionally, some irrigation schemes in the Abay basin with scheme boundaries fall within the range of 29.2% (62.33 km²) of high suitability and 70% (149.2 km²) of moderate suitability of these study results. The irrigation potential in
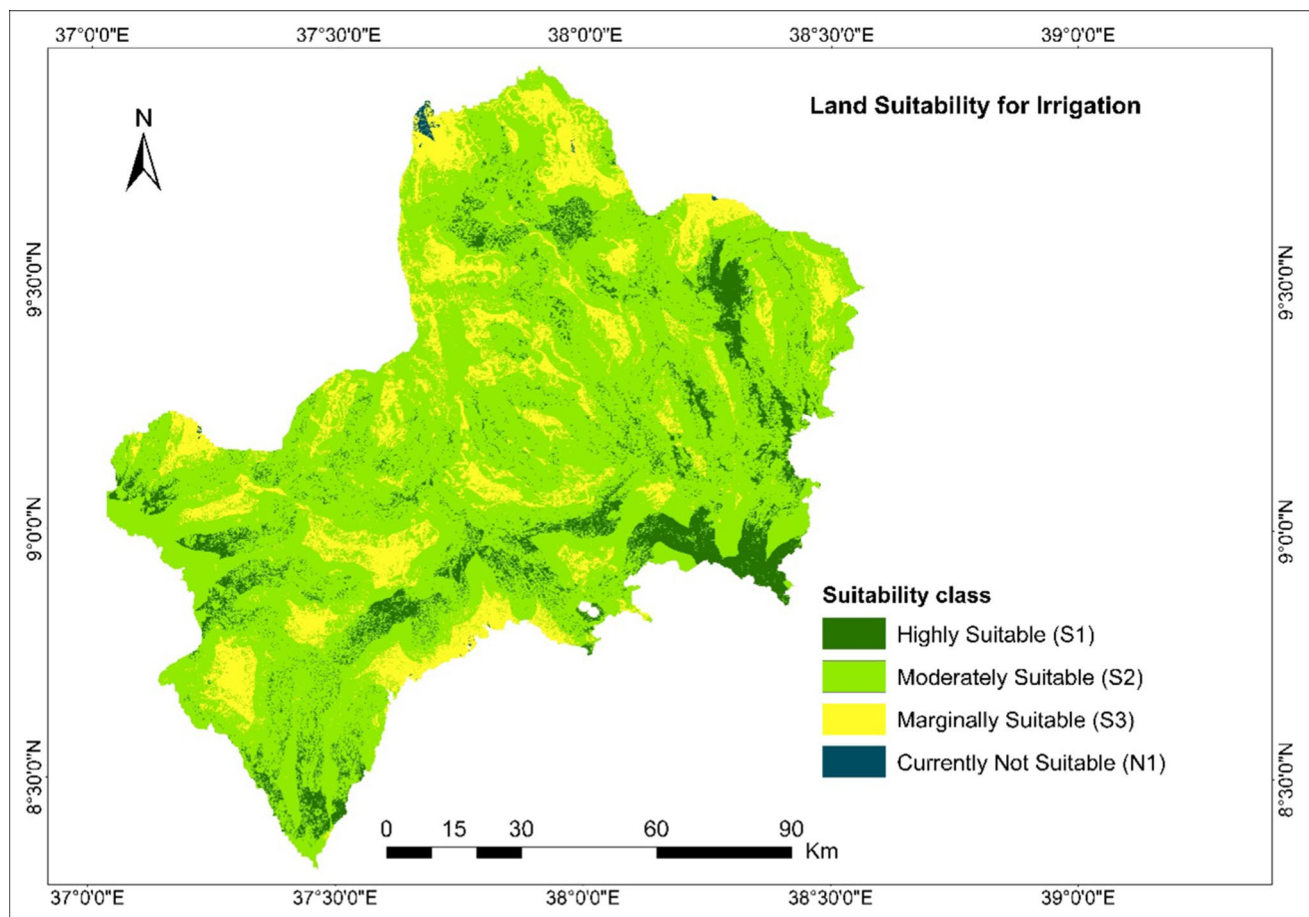
Fig. 14 Map of land suitability for irrigation

Table 10 Distribution of land suitability for irrigation

S/N	Suitability	Area per each suitability class (km^2)	% per each suitability class (%)
1	S1	1419.87	10.27
2	S2	10,128.97	73.23
3	S3	2259.95	16.34
4	N1	22.16	0.16

the study area was also evaluated by the Oromia irrigation development authority in 2018 with a focus on the zones and woredas. The irrigation potential of the West Shewa zone was also assessed. The study revealed that 10,316 km^2 of the West Shewa zone is highly and moderately suitable land for irrigation and related to the present study, in which the highly and moderately suitable land is 83.5% (11,548.84 km^2). Table 12 displays the results of the existing and potential irrigation areas in the West Shewa zone, which were obtained from the zonal irrigation development bureau. It indicates only irrigated agricultural land, which differs from rain-fed agricultural land.

Conclusion

The study assessed land suitability for irrigation using GIS-based multi-criteria evaluation in the West Shewa zone, Oromia, Ethiopia. The multi-criteria analysis was evaluated using the analytical hierarchy technique. The criteria considered are slope, soil properties, land use/cover, river networks, road networks, urban centers, and rainfall deficit. The results obtained were based on a suitability scale suggested in the FAO framework. According to the results, 10.27% of the area was highly suitable, 73.23% moderately suitable, 16.34% marginally suitable, and 0.16% currently not suitable. Additionally, the distribution of the land suitability classes in all woreda was assessed, and maximum highly

Table 11 The area and % age of land suitability classes in the woreda

S/N	Woreda	Area per each suitability class (km²)				Total (km²)	% per each suitability class (%)			
		S1	S2	S3	N1		S1	S2	S3	N1
1	Metarobi	155.08	675.64	155.55	0.88	987.15	61.7	36.31	1.9	0.09
2	Jibat	32.13	377.78	71.21		481.12	6.68	78.52	14.8	
3	Midakegn	27.9	637.25	127.32		792.47	3.52	80.41	16.07	
4	Cheliya, Elu Gelan	97.89	888.75	115.81		1102.45	8.88	80.62	10.5	
5	Elfata	10.82	364.93	36.87		412.62	2.62	88.44	8.94	
6	Abuna G/beret	55.16	660.16	297.15	0.98	1013.45	5.44	65.14	29.32	0.1
7	Nono	139.31	582.87	14.88		737.06	18.9	79.08	2.02	
8	Dano	37.81	461.52	136.26	0.03	635.62	5.95	72.6	21.44	0.01
9	Dire Enchinni	77.7	313.89	160.93	1.75	554.27	14.02	56.63	29.04	0.31
10	Bako Tibe	46.27	488.34	112.25	1.01	647.87	7.14	75.38	17.32	0.16
11	Ejere	215.7	356.76	1.36		573.82	37.59	62.17	0.24	
12	Dandi, Ejersa Lafo	238.19	839.55	112.26		1190	20.02	70.55	9.43	
13	Ambo	112.51	861.95	182.56		1157.02	9.72	74.5	15.78	
14	Toke, Liban Jawi	36.47	341.13	154.2	0.42	532.22	6.85	64.1	28.97	0.08
15	Jeldu, Chobi	51.04	998.5	227.91		1277.45	4	78.16	17.84	
16	G/beret	81.52	870.59	294.12	18.2	1264.45	6.45	68.85	23.26	1.44
17	Adea Berga	76.27	794.79	112.2		983.26	7.76	80.83	11.41	

Table 12 Potential and actual irrigated area in the West Shewa zone

S/N	Type of scheme	No. of schemes	Actual irrigated area, ha	Potential irrigable area, ha	Current status	
					Functional	Non-functional
1	Modern irrigation	65	3486.67	4350.98	64	1
2	Traditional	2132	30,605.40	42,561.56	2118	13
3	Pump	867	5878.63	8658.47	766	101
4	Shallow well	5457	346.41	545.72	5317	131
5	Pond	10	1.81	101	10	
	Total	8531.00	40,318.92	56,217.73	8275	246

and moderately suitable lands were found in Metarobi and Elfata woreda, respectively. Thus, the suitability classification assures us that the study area has huge potential land for irrigation development. However, further study is required for irrigation development considering more factors such as water availability, crop water requirements, climate variability, and economic feasibility. Through progressive refining and considering many factors, the suitable land obtained in this study can be reduced to a more accurate irrigable land potential. However, it can be a baseline for future researchers, planners, and decision makers by modifying it with the most recent dataset and considering all the required criteria. Therefore, this study can improve the agricultural production and the livelihoods of rural people in the study area.

Declarations

References

Assefa T, Jha M, Reyes M, Srinivasan R, Worqlul AW (2018) Assessment of suitable areas for home gardens for irrigation potential, water availability, and water-lifting technologies. Water 10(4):1–21. https://doi.org/10.3390/w10040495

Awulachew SB, Yilma AD, Loulseged M, Loiskandl W, Ayana M, Tena A (2007) Water Resources and Irrigation Development in Ethiopia. In: Iwmi: Working Paper

Balew A, Nega W, Legese B, Semaw F (2021) Suitable potential land evaluation for surface water irrigation using remote sensing and GIS–MCE in the case of Rib-Gumara watershed, Ethiopia. J Indian Soc Remote Sens 49(9):2273–2290. https://doi.org/10.1007/s12524-021-01383-w

Bekele T (2008) Limitation and potential of major soils in the highlands of West Shewa, Ethiopia pp 50–61 http://hw.oeaw.ac.at/?arp=0x001a2887

Congalton RG (1991) A review of assessing the accuracy of classifications of remotely sensed data. Remote Sens Environ 37(1):35–46. https://doi.org/10.1016/0034-4257(91)90048-B

Congalton RG (2001) Accuracy assessment and validation of remotely sensed and other spatial information. Int J Wildland Fire 10(3–4):321–328. https://doi.org/10.1071/wf01031

DAS AC (2021) Land Suitability Evaluation and Drought Stress Assessment of Tea Estates Using Satellite Remote Sensing-based Multi-Criteria Decision Support System July 2021 ANIMESH CHANDRA DAS Land Suitability Evaluation and Drought Stress Assessment of Tea Estates Usi July

FAO (1976) A framework for land evaluation. FAO soils bulletin 32. Rome, Italy. Land and water division, Food and Agriculture Organization of the United Nations (FAO)

Hagos YG, Mengie MA, Andualem TG, Yibeltal M, Linh NTT, Tenagashaw DY, Hewa G (2022) Land suitability assessment for surface irrigation development at Ethiopian highlands using geospatial technology. Appl Water Sci 12(5):1–11. https://doi.org/10.1007/s13201-022-01618-2

Haile MM (2022) Application of geospatial technology coupled with fuzzy logic operations in mapping soil-erosion critical zones: the case of guder sub-basin, upper blue nile basin, ethiopia. Appl Water Sci 12:195. https://doi.org/10.1007/s13201-022-01717-0

Haile MM, Abebe AK (2022) GIS and fuzzy logic integration in land suitability assessment for surface irrigation: the case of Guder watershed, upper blue Nile Basin. Ethiopia Appl Water Sci 12:240. https://doi.org/10.1007/s13201-022-01761-w

Haile MM, Tafesse Yadeta J, Amena Gambe L (2022) Delineation of groundwater potential zones using geo-spatial and AHP techniques: Ambo area, blue Nile Basin. Ethiopia Sustain Water Resour Manag 8:36. https://doi.org/10.1007/s40899-022-00622-3

Hussien K, Woldu G, Birhanu S (2019) A GIS-based multi-criteria land suitability analysis for surface irrigation along the erer. East African J Sci 13(2):169–184

Kiran M, Amare H, Semu A (2020) NBI Technical reports : water resources management series mapping land suitability for irrigation in the Nile basin.

Liu F, Peng Y, Zhang W, Pedrycz W (2017) On consistency in AHP and fuzzy AHP. J Syst Sci Inf 5(2):128–147. https://doi.org/10.21078/jssi-2017-128-20

Mazahreh S, Bsoul M, Hamoor DA (2019) GIS approach for assessment of land suitability for different land use alternatives in semi arid environment in Jordan: case study (Al Gadeer Alabyad-Mafraq). Inf Process Agric 6(1):91–108. https://doi.org/10.1016/j.inpa.2018.08.004

Haile MM (2022) Approaches for delineating groundwater recharge potential zone using fuzzy logic model. Geofluids. https://doi.org/10.1155/2022/3637230

Mideksa G, Temesgen T (2020) Irrigation water potential and land suitability assessment in kurfa chele-. Turk J Agric Food Sci Technol 8(1):139–146

Nigussie G, Moges MA, Moges MM, Steenhuis TS (2019) Assessment of suitable land for surface irrigation in ungauged catchments: blue Nile Basin. Ethiop Water 11(7):1–17. https://doi.org/10.3390/w11071465

Rikitu A, Emana B, Haji J, Bekele K (2019) Smallholder farmers' decision to participate in vegetable marketing and the volume of sales in west shewa zone of oromia national regional state. Ethiop Sustain Agric Res 8(4):48. https://doi.org/10.5539/sar.v8n4p48

Saaty TL (1977) A scaling method for priorities in hierarchical structures. J Math Psychol 15(3):234–281. https://doi.org/10.1016/0022-2496(77)90033-5

Sarkar A (2018) Accuracy assessment and analysis of land use land cover change using geoinformatics technique in raniganj coalfield area India. Environ Sci Nat Resour 11(1):25–34. https://doi.org/10.19080/IJESNR.2018.10.555805

Worqlul AW, Collick AS, Rossiter DG, Langan S, Steenhuis TS (2015) Assessment of surface water irrigation potential in the Ethiopian highlands: the lake tana basin. CATENA 129:76–85. https://doi.org/10.1016/j.catena.2015.02.020

Worqlul AW, Jeong J, Dile YT, Osorio J, Schmitter P, Gerik T, Srinivasan R, Clark N (2017) Assessing potential land suitable for surface irrigation using groundwater in Ethiopia. Appl Geogr 85:1–13. https://doi.org/10.1016/j.apgeog.2017.05.010

Worqlul AW, Dile YT, Schmitter P, Jeong J, Meki MN, Gerik TJ, Srinivasan R, Lefore N (2018) Clarke N (2019) Water resource assessment, gaps, and constraints of vegetable production in Robit and dangishta watersheds, upper blue Nile basin Ethiopia. Agric Water Manag 226:105767. https://doi.org/10.1016/j.agwat.2019.105767