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Irrigation Land Suitability Assessment of Sibilu River Catchment using Geographic Information System

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Abstract

It is critical to assess land suitability for irrigation to make efficient and effective use of limited resources for agricultural production that is sustainable. Using a geographic information system, the researchers determined the physical irrigation suitability of the Sibilu River watershed. The most suitable land was determined using a weighted overlay of irrigation suitability characteristics such as slope, soil, and land use land cover. A double mass curve was used to check for inconsistencies in the data, and the normal ratio approach was used to fill in the missing metrological data. The final irrigable land was found by weighting the elements of appropriateness, which were categorized based on the food and agricultural organization standard for land evaluation into highly suitable, moderately suitable, marginally acceptable, and not suitable classifications. According to the irrigation suitability analysis parameters, 56.5 percent of the slope, 19.3 percent of soil, and 89.82 percent of land use/cover area were all extremely suitable for surface irrigation. Overall, the weighted overlay analysis of these characteristics revealed that 57.53 percent of the research region was extremely favorable for irrigation development, whereas 0.42 percent was deemed to be unsuitable. In terms of adaptability parameters, the Sibilu River is very ideal for surface irrigation. However, because only 133 hectares could be irrigated, dry flows should be augmented or groundwater should be developed and water conserved to meet irrigation potential.

Keywords: GIS • Irrigation potential • Land suitability • Sibilu catchment

Introduction

According to studies, by 2050, 70 percent of additional food production will be necessary to meet global food demand, with 100 percent for emerging countries [1]. This demonstrates that, in comparison to affluent countries, the increase in food consumption for developing countries is relatively large, and this is also true for Ethiopia. Ethiopia's population has been growing, and it now numbers around a hundred million people [2]. Because the supply of land is constant, an extensive system of increasing agricultural products may not be sufficient to feed this rapidly growing population. Irrigation is critical to food production, but it has fallen short of expectations in Sub-Saharan Africa until recently [3]. Many places in the Oromia region are vulnerable to issues caused by a lack of rainfall. This is especially true for Sululta district, which has been impacted by rainy season delays and early cessation in recent years [4].

Ethiopia has a large potential for developing water and land resources for irrigation, which could contribute to long-term food security. Ethiopia has 12 major river basins, nine of which are wet and three of which are dry, with annual runoff volumes of 122 billion m^3 of surface water and 2.6 billion m^3-6.5 billion m^3 of groundwater potential [5]. Despite the abundance of water, around 10% of Ethiopia's population receives food aid [6]. With available surface water resources, Ethiopia is expected to have 3.7 million hectares of potentially irrigable land, while acreage irrigated through the establishment of traditional and modern irrigation systems is estimated to be about 386,603 hectares, or about 10% of potentially irrigable land [7]. Food shortages have become more common as a result of a combination of population expansion, land degradation, and more frequent droughts. As a result, irrigation development is seen as a collection of solutions that can resolve the conundrum [8]. Nonetheless, in the Ethiopian context, there is no consistent and trustworthy inventory or well-studied record on water and irrigation-related potentials [9].

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Rain-fed agriculture and seasonal farming are the predominant agricultural practices in the country and the research area, respectively. Rainfall agriculture is characterized by a high degree of fluctuation and unreliability. Irrigation is required to reduce the impact of rainfall unpredictability and to enhance the number of annual, perennial, and commercial crops that can be irrigated year round with a controlled water supply [10]. While Ethiopia has a lot of potential to irrigate its agriculture, rain-fed agriculture produces 97 percent of the country's food crops, while irrigated agriculture produces only 3% [11].

The high degree of rainfall fluctuation and unreliability in the country is the country's biggest concern with rainfall dependent agriculture. Crop failures due to dry spells and droughts are common as a result of this unpredictability. Due to technical, physical, and economic obstacles, there is a large gap between the potential and the degree of irrigation implemented in the country, although the factors of irrigation participation are not thoroughly defined in specific areas of the country [12]. As a result, even the tiniest adverse climatic event might turn into famine, harming the livelihoods of the rural poor. As a result, irrigation development, which can lead to security by reducing harvest volatility, as well as crop intensification by growing more than one crop per year, could be a solution to food insecurity [13].

In irrigated agriculture, the use of water resources provides additional and full-season irrigation to combat the effects of rainfall variability and unreliability. As a result, rather than relying solely on rain-fed crop cultivation, irrigated agriculture has the potential to reduce regional and temporal production variability [14].

GIS is a computer-based system that provides a convenient and powerful platform for doing suitability evaluations, as well as data entry, analysis, and display, as well as data integration across several layers [15]. During the last decade, GIS has aided in the identification and evaluation of viable solutions to water resource issues [16]. The ability of GIS to manipulate various types of data makes it a preferable technology for studying the irrigation potential of a basin with an evaluation of water resources and currently irrigated area because it allows for more efficient complex analysis extracting information about spatially distributed phenomena [17].

The FAO criteria for determining land suitability for prospective surface irrigation were followed [18]. The soil, slope, and land cover/use were weighted and evaluated using ArcGIS to determine which areas would be ideal for irrigation. Because no study based on weighting land resources for irrigation potential had been undertaken in the study region, this study was supplemented with some assets to investigate the irrigation resource (potential) in the study area. Furthermore, the study area's potentially irrigable areas have yet to be discovered and matched with the water requirements of some of the products grown there [19].

There is a need to create an irrigation potential assessment due to recurrent food insecurity and the rising quantity and complexity of poverty. For better use of land resources for irrigation, proper evaluation and assessment of the potential and appropriateness of the land area are critical [20]. There is a high water resource potential and restricted irrigation in the research area, with no previous resource potential assessment and evaluation and no water resource potential assessment. As a result, this study was proposed to use the GIS to analyze the study area's prospective appropriateness for irrigation.

Materials and Methods

Data collection and sources

Secondary data was employed to acquire information for this investigation. Secondary data was gathered from a variety of sources, including the Ministry of Water, Irrigation, and Energy (MoWIE), the National Metrology Agency (NMA), and the Ethiopian Map Agency (EMA).

To achieve the goals outlined, various types of data were employed to analyze the irrigation potential of the research area. Spatial data (DEM, LULC, and Soil), hydrological data (Streamflow), and metrological data were examples of such data.

Tools and materials

The following tools were used to evaluate the study's irrigation potential: Microsoft Excel worksheet for rearranging data inputs.

ArcGIS is a Geographic Information System (GIS) that may be used to create maps and assess suitability.

CROPWAT 8.0 is a program that calculates ETo and agricultural water requirements.

Analysis and processing

Data collected may contain mistakes as a result of measuring device or recording issues. As a result, before using the data for a specific purpose, it was reviewed for inaccuracies and corrected. Checking for consistency in rainfall data filling in missing metrological data.

Watershed delineation: Using ArcGIS, a DEM of the research region was derived from the Abay basin DEM. Abay DEM was filled using ArcGIS' fill tool. The filled raster map was then used to create a flow direction raster map. A flow accumulation map was created using the flow direction raster map. The sibilu river's discharge point (where it meets the Abay River) was discovered on the flow accumulation map and converted to a point shapefile. This point shapefile was used to make a snap pour point. The sibilu watershed was then defined using this pour point and flow accumulation raster. The raster map of the sibilu watershed was transformed into a polygon shapefile map.

DEM for the Sibilu watershed was extracted using a raster processing tool, Abay filled DEM and Sibilu watershed polygon.

Topography: The research area's geography ranges from mountain chains in the South surrounding the Entoto ridge to plains in the East, North-West, and North. The study area's average elevation is 2530 m above mean sea level, as shown in Figures 1 and 2 [21].

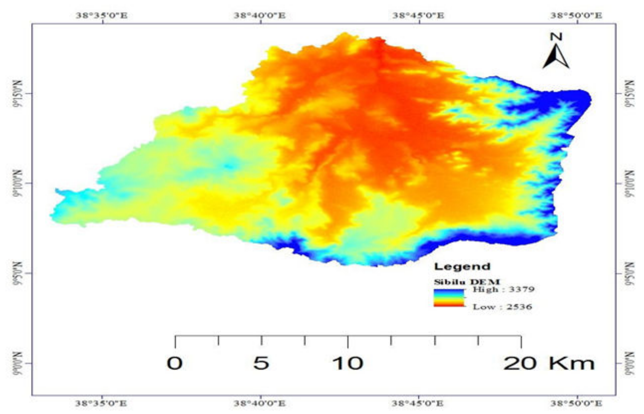

Figure 1. Digital elevation model of sibilu river.

Identification of potential irrigable sites: The slope, soil, and land cover/use were all taken into account while determining potential irrigation sites. By analyzing slope appropriateness analysis and soil suitability evaluation, the individual suitability of each element was first examined and then weighted to arrive at possible irrigable sites.

Evaluation of soil suitable for irrigation: The research area's soil as indicated in Table 1 and the suitability for surface irrigation was analyzed in terms of soil physical properties such as soil texture, soil type, soil depth, as well as soil drainage. They have an impact on plant root growth, water infiltration into the soil, and crop output.

The suitability of soil types for irrigation, according to (FAO, 1998), is Chromic Luvisol and Eutric Vertisol (S1), Eutric Cambisols (S2), and Eutric Leptosols (S3) (N).

Cambisols are soils that are still in the process of forming or are developing soils that are related to their parent material. Cambisols are medium-textured soils with excellent porosity and strong water retention. Leptosols are soils having an incomplete column and morphological traits that are not fully expressed. They are particularly widespread in the hilly to the mountainous area of the study area's southern margin, which accounts for only a small amount of the total area. They have a modest water holding capacity and are free draining. Luvisol is a type of soil that has an argic subsurface horizon and is found mostly on flat or moderately sloping ground. Because of its intermediate stage of weathering and high base saturation, Luvisol has adequate internal drainage and may be useful for a wide range of agricultural applications. Vertisols are soil types that have a homogeneous particle size distribution, good water retention qualities, and high cation exchange and base saturation. As a result, it is suitable for irrigation [22].

Soil type	Area (ha)	Area (%)
Eutric cambisols	15370.34	33.57
Eutric vertisols	17707.64	38.68
Chromic luvisol	8843.1	19.31
Eutric leptosols	3863.4	8.44

Table 1. Major soil types in the study area.

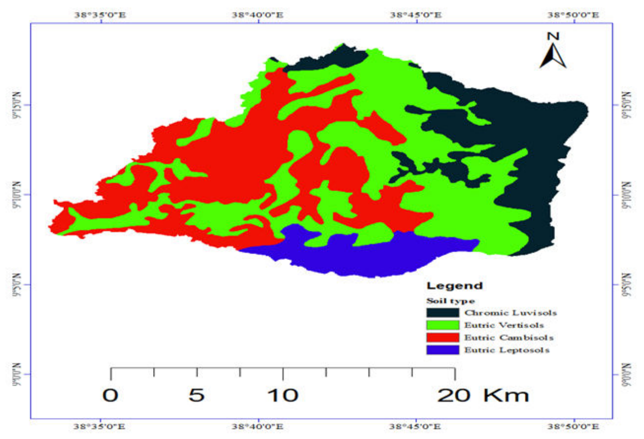

Figure 2. Soil map of the study area.

Land use/cover analysis: The study area's land use/cover were also considerations in determining the land's suitability for irrigation. The ethiopian mapping agency provided the land use map for the research area. The study area's land use/cover types were ranked according to their irrigation potential. The cost of irrigation to prepare land for agriculture is influenced by land use/cover. Perennial crops were among the forms of land use/cover studied. Closed grassland, annual crop grassland, moderate forest mixed forest woodland wetland, settlement and the factors for irrigation suitability (Table 2 and Figure 3).

Factor	Specific factor	Derivation	Sources
Slope	Slope factor	DEM	MOWIE
Soil	Soil factors	Soil map	MOWIE
Land use/cover	Land use/cove factors	Land use/cover map	EMA

Table 2. Factors for assessment of irrigation suitable land with their derivation and sources.

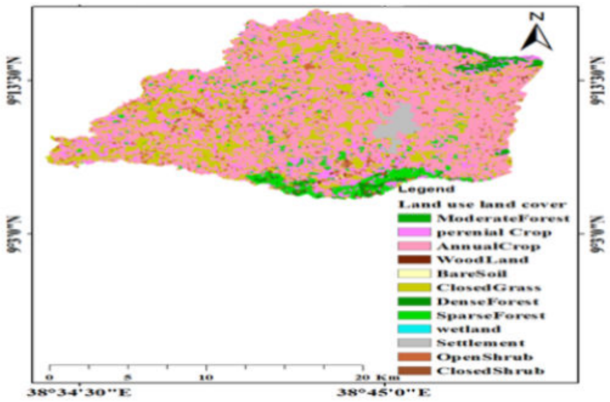

Figure 3. Land use the land cover map.

Developing the pairwise comparison

Pairwise comparisons were assessed to determine appropriate alternatives for estimating associated absolute numbers from 1 to 9 for each factor. The team with the highest score indicates that the row was more essential than the column. The matrix's diagonal was given a score of one. The value in the corresponding column just below the diagonal was the exact inverse of the score in the corresponding row as we moved down the column.

A formula from the matrix goal calculation was used to calculate the consistency ratio.

Weighing of irrigation suitability factors to find potential irrigable sites

A suitability model was developed using the model builder in the Arc tools box and tools from the spatial analysis toolsets to determine a suitable site for surface irrigation. The irrigation suitability factors that were evaluated in this study, such as slope, soil, and land cover/use factor, were then utilized as input for the irrigation suitability model to discover the most suitable land for surface irrigation after assessing their suitability.

Calculating water requirements for irrigation

Assessing the irrigation water needs can be used to determine the irrigation potential depending on soil and water resources. The equation can be used to calculate ETc from E (FAO, 156).

$$ETc = ETKc \qquad (1)$$

Where Kc is crop coefficient, ETc is crop evapotranspiration (mm/day), and ETo is reference evapotranspiration (mm/day).

Net Irrigation Water Requirement (NIWR): It's the amount of moisture that needs to be provided by irrigation to meet the crop's evapotranspiration needs minus effective rainfall. The net irrigation demand can be expressed as follows:

$$NIR = ET - PE \qquad (2)$$

Where PE is effective rainfall, ET is the crop water requirement.

Gross Irrigation Water Requirement (GIWR): The net irrigation water requirement is divided by irrigation efficiency to get the gross irrigation water requirement. It is described as follows: The optimum irrigation efficiency for Ethiopia's highlands is 50%.

$$GIWR = \frac{\text{NIR}}{\text{E}} \qquad (3)$$

Where E is Irrigation efficiency

Results and Discussions

Irrigation suitability

The slope, soil physical qualities, and land use land cover factors were used to characterize the analysis results of surface irrigation suitability parameters as shown in Figure 3.

Slope suitability: The results of the slope analysis of the research area, which were divided into four suitability classes (S1, S2, S3, and N) (Table 3 and Figure 4).

Slope range (%)	Area coverage (ha)	Area coverage (%)	Suitability classes	Suitability class name
0-2	25877.79	56.5	S1	Highly suitable
02-May	12825.81	28	S2	Moderately suitable
05-Aug	4906.44	10.72	S3	Marginally suitable
>8	2175.03	4.75	N	Not suitable

Table 3. Slope suitability of the study area for surface irrigation.

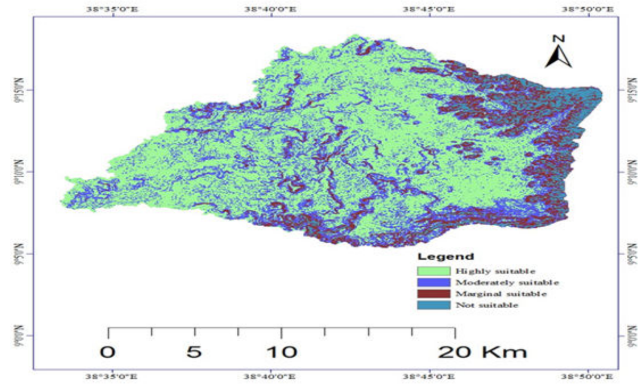

Figure 4. Slope suitability map of the study area.

Texture of the soil: According to the findings of the soil texture analysis, the research area can be divided into two irrigation suitability classes: Highly suitable (S1) and moderately suitable (S2). The soil textural class clay and loam were assessed as extremely suitable (S1) and appropriate for irrigated agriculture by the. The study area's soil texture classes were constructed based on Figure 5. Clay, clay loam, and loam were classed as extremely appropriate for irrigation, covering 91.61 percent (41824.08 ha), whereas sandy clay was moderately suitable for irrigation, covering 8.39 percent (3830.4 ha). Clay, clay loam, loam, and sandy clay soil were the most common soil textures in the research region. In irrigated agriculture, clay soil has the advantage of being able to store more water than sandy clay soil, as well as being high in nutrients and water holding capacity. In terms of soil texture suitability, clay soil was deemed very suited for surface irrigation (Figure 5).

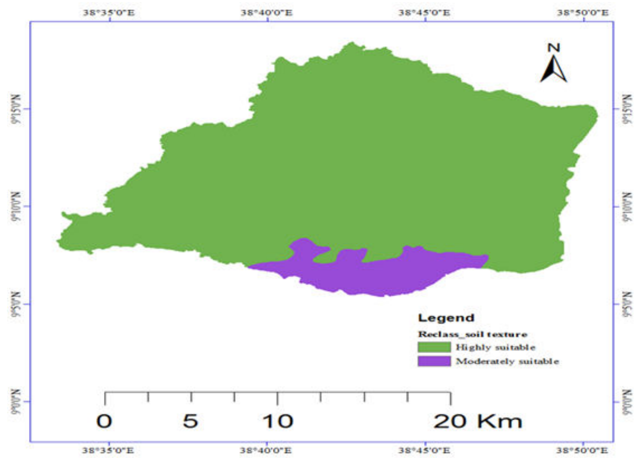

Figure 5. Soil texture suitability map of the study area.

Soil type: Soil types in the study area were divided into three irrigation suitability groups based on soil suitability: S1 (very suitable), S2 (moderately suitable), and N (not suitable). Vertisols and Luvisols, which cover 58 percent (26485.74 ha) of the study area and are soils with natural fertility and suitability for a wide range of agriculture uses and are very productive, were classified as highly suitable (S1) for surface irrigation, cambisols, which cover 33.6 percent (15338.34 ha) of the study area and have good natural fertility and are suitable for agricultural uses, were classified as moderately suitable (S2), and leptosols, which as a result, the majority of the research area was ideal for surface irrigation (Figure 6).

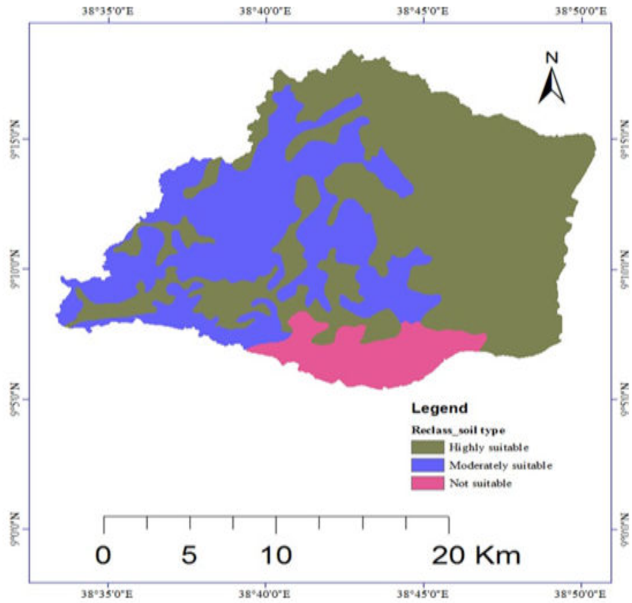

Figure 6. Suitability map of soil type of the study area.

Soil depth: Crops rely on the depth of the soil for structural support, nutrients, and water. Based on soil depth appropriateness as a consideration, the study region may be categorized into three irrigation suitability classes, as indicated in Table 4. The overall area was assessed as extremely appropriate for surface irrigation in 61.23 percent (27956.4 ha), moderately suitable in 35.91 percent (16396.5 ha), and not suitable in 2.85 percent (1301.58 ha).

Soil depth	Area (ha)	Area (%)	Suitability rating	Suitability class
1,30,100	27956.4	61.23	S1	Highly suitable
80	16396.5	35.91	S2	Moderately suitable
30	1301.58	2.85	N	Not suitable

Table 4. Soil depth suitability of the study area.

The soil depth suitability map of the study area for surface irrigation potential was developed in Figure 7 based on the given weighting factors for each soil depth of the study area. Most of the upper part of the study area was highly suitable for surface irrigation suitability, while the lower part of the study area was not suitable for surface irrigation suitability.

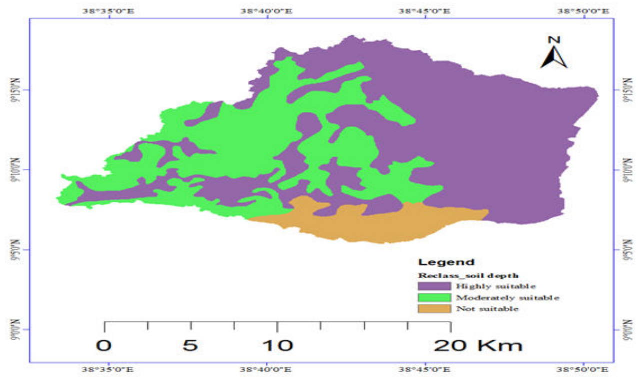

Figure 7. Suitability map of soil depth of the study area.

Soil drainage: The study area's soil drainage was categorized into three types. In terms of drainage soil appropriateness, the majority of the research locations were well-drained. Table 5 reveals that 52.89 percent (24148.44 ha) was well-drained, which was classed as extremely suitable, 38.72 percent (17675.64 ha) was imperfectly drained, which was rated as marginally acceptable, and the remaining 8.39 percent (3830.4 ha) was not suitable for surface irrigation.

Soil drainage	Area (ha)	Area (%)	Suitability factor	Suitability class
Well-drained	24148.44	52.89	S1	Highly suitable
Imperfectly drained	17675.64	38.72	S3	Marginally suitable
Poorly drained	3830.4	8.39	N	Not suitable

Table 5. Soil drainage of the study area

As a result, the bulk of the research area proved ideal for surface irrigation development. The Luvisol was well drained due to its high-water holding capacity, but the leptosol was badly drained due to its low water holding capacity and insufficient nutrients. The suitability map of soil drainage created from the rasterized soil map of the study area indicated in Figure 8 that most areas of the study area were very appropriate for surface irrigation.

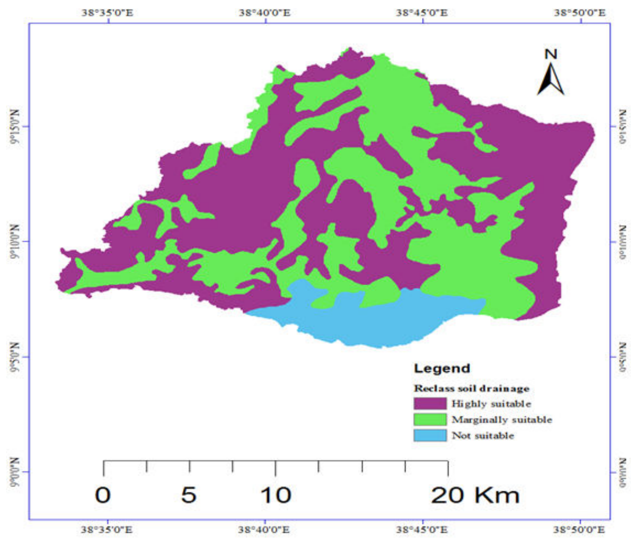

Figure 8. Suitability map of soil drainage of the study area.

Land use/land cover suitability

The Ethiopian mapping agency provided us with a land use map of the research area. Land usage of the research area's land cover, such as cultivated and grassland, was assessed as highly appropriate for irrigation, assuming that these land cover classes can be irrigated without restriction. Other land uses such as wood and pasture land were classed as somewhat acceptable with an area of 6.05 percent (2760.48 ha) while forest and settlement areas with an area of 4.42 percent were not suitable for surface irrigation (2015.55 ha). As a result, in terms of land use land cover suitability, the majority of the studied region fell into the high to marginal category. Table 6 shows that the land cover of the research region was highly appropriate for surface irrigation, with 41008.5 hectares of land use.

Because there will be no land clearing preparatory costs or forest degradation, farmed land was regarded as highly suited for surface irrigation, as shown in Figure 9 and Table 6. Furthermore, these land cover classes can be irrigated without or with minimal land removal and farm preparation costs.

Because of their work efficiency, the expense of land clearing, and land preparation for irrigation, wood, and pasture land are rated as minimally appropriate for irrigation. Because they are restricted to use for irrigation and there is no irrigation practice in the land cover, forest and settlements were deemed unsuitable for surface irrigation.

Land use/cover factor	Area (ha)	Area (%)	Suitability factor	Description
Cultivated and grass land	41008.5	89.82	S1	Highly suitable
Wood and grazing land	2760.48	6.05	S3	Marginally suitable
Forest and settlement	2015.55	4.42	N	Not suitable

Table 6. Major land use/land cover types of the study area.

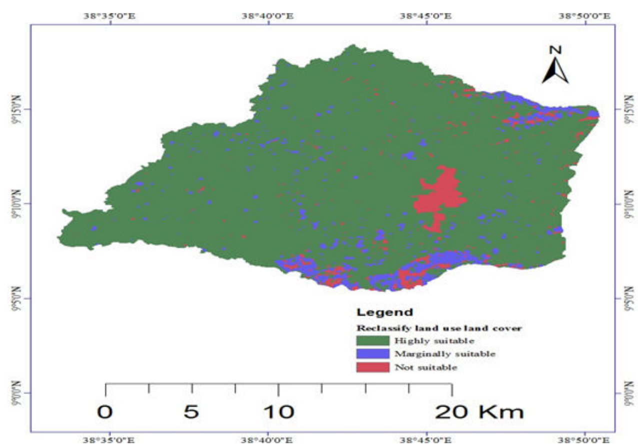

Figure 9. Suitability of land use land cover map of the study area.

Suitable land for irrigation

The irrigation suitability model study was used to determine potentially irrigable land, which included weighing the values of all suitable parameters such as slope, soil, and land use land cover.

The results shown in Figure 10 reveal that most areas of the research region were assessed as very appropriate to moderately acceptable for surface irrigation potential developments in terms of overall suitability analysis.

The overall irrigation suitability results were described in Table 7. Highly suitable area for surface irrigation covered an area of 57.53 percent (26247.33 ha), moderately suitable was 35.89 percent (16373.43 ha), the marginally suitable area covered 6.17 percent (2813.13 ha), and 0.42 percent (191.7 ha) of the study area categorized as not suitable for surface irrigation. As a result, the majority of the study areas were categorized as highly suitable to moderately suitable for surface irrigation.

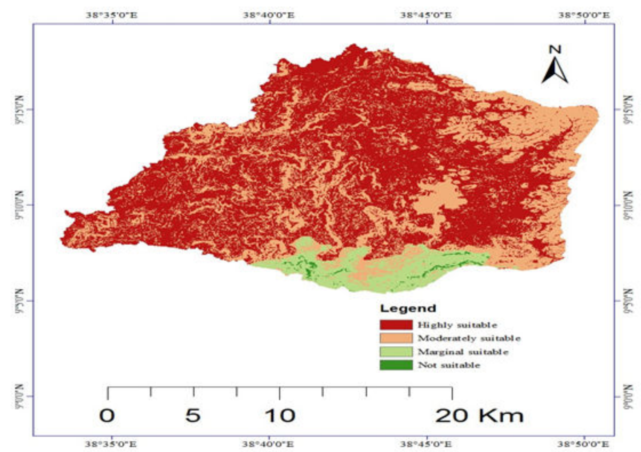

Figure 10. Final irrigable land suitability map of Sibilu river catchment.

The overall irrigation suitability results were described. Highly suitable area for surface irrigation covered an area of 57.53% (26247.33 ha), moderately suitable was 35.89% (16373.43 ha), the marginally suitable area covered 6.17% (2813.13 ha), and 0.42% (191.7 ha) of the study area categorized as not suitable for surface irrigation. Therefore, most of the study areas ranged from highly suitable to moderately suitable for surface irrigation in terms of overall suitability [23].

Area ha	Area (%)	Suitability factor	Description
26247.33	57.53	S1	Highly suitable
16373.43	35.89	S2	Moderately suitable
2813.13	6.17	S3	Marginal suitable
191.7	0.42	N	Not suitable

Table 7. Overall surface irrigation suitability.

Conclusion

Irrigation suitability testing was done on suitable irrigable land in the study area, and a final suitability map was created. Slope, soil type, soil texture, soil depth, soil drainage, and land usage land cover were the key irrigation appropriateness criteria investigated during the study.

The geographic information system, excel spreadsheet, and CROPWAT were utilized to analyze the irrigation potential of this study. Secondary data was gathered from the Ethiopian mapping agency, the ministry of water, irrigation, and electricity, and the national metrological agency. A double mass curve was used to check for inconsistencies in the gathered data, and the missing metrological data were filled using the normal ratio approach.

The suitability of irrigation was determined using FAO recommendations, which included highly suitable (S1), moderately suitable (S2), marginally acceptable (S3), and not suitable (S4) (N). The land cover of the research region was determined as very suitable for surface irrigation based on the analysis of 56.5 percent of the slope, 19.3 percent of soil, and 89.82 percent of land usage. Surface irrigation was deemed unsuitable in 4.75 percent of slopes, 8.39 percent of soil, and 4.42 percent of land use land cover. The potential irrigation lands for irrigation were 57.53 percent highly suitable, 35.89 percent moderately suitable, 6.17 percent marginally suitable, and 0.42 percent not suitable for irrigation development when these characteristics were weighted using overlay in Arc GIS.

In terms of land suitability characteristics, the study region was rated as highly to marginally favorable for surface irrigation potential.

Acknowledgment

First and foremost, we would like to thank our team members for their professional contributions and constructive comments during the research period. Our acknowledgments are also extended to the ministry of water irrigation and electricity, ethiopian mapping agency, and national metrological agency for their cooperation in providing relevant data. Lastly, we express our gratitude to all our friends who have helped us with this research.

Competing of Interest

The authors had participated in this research and institutions have no complaint of interest that could have appeared to influence the work reported in this paper.

Data Availability

All data generated or analyzed during this study are included in this manuscript. The raw data that support the findings of this study are collected from the ministry of water, irrigation, and energy, the national metrology agency, and the ethiopian map agency. The authors have no authority to openly distribute those data.

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