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**Research Article**

# GIS-based irrigation potential assessment on Shaya River sub-basin in Bale Zone, Oromia region, Ethiopia

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**Abstract:** The principal objective of this study was to evaluate the land resources potential of the fertile Shaya River sub-basin for irrigation and amply providing a Geo-referenced map of these valuable resources using Geographical Information System (GIS) techniques. Suitability factors considered to identify the potentially irrigable land were the slope, texture, depth, drainage characteristics, land use/cover and distance to a water source. The suitability analysis of the parameters indicates that slope 66.38%, soil 98.20% and land use/cover 92.93% of the study areas classified as potentially suitable for irrigation development in the study area. By weighing analysis of all parameters, 22.05% of the study area was found to be highly suitable, 25.27% moderately suitable and 16.20% marginally suitable whereas about 33.57% restricted for irrigation developments. By comparing the required water and available monthly flow of the river, the river possesses the capacity for the application of the command area.

***Keywords***: *irrigation potential, land suitability, Shaya river basin, soil analysis*

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## Introduction

Nowadays, the earth's population is growing dramatically. Today's world population of 7.6 billion is expected to reach about 11.1 billion by 2100 (UN, 2017). The growing population will result in considerable additional demand for food. FAO analyzed agricultural production for over 90 less developed countries, and the result shows that from the period 1998 – 2030 it increases by 49% in rain-fed agriculture and by 81% by irrigation. Therefore, a higher number of additional foods expected from an irrigation system (Bahmani et al., 2013).

Ethiopia's population estimated at 98,352,000 million (CSA, 2016) and Most of the people in Ethiopia lives in the highland area, with 85 percent being rural and dependent on agriculture with a low level of productivity (Awulachew et al., 2007; Bekele et al., 2012). Ethiopia is prosperous with natural resources like land and water that helps the Socio-economic development of the country. The country is endowed with ample water resources with 12 river basins with an annual runoff volume of 124.5 billion m3 of water and an estimated 2.86 billion m3 of groundwater potential (Makombe et al., 2011; MoA, 2011a) and about 73.6 million ha (67%) had identified as potential agricultural land (Fasil, 2002)

Agriculture is the core driver for, growth and long-term food security in Ethiopia and the development of irrigation in this country is small and not contributing its share to the growth of the agriculture sector accordingly. About 15 to 17% of Government expenditures are committed to the agriculture sector, which directly supports 80% of the population's livelihoods, 47% of gross domestic product (GDP) and over 83.9% of export value (FDRE, 2011). But the country has the potential for its development both regarding vast suitable land and availability of freshwater resources adequate for irrigation purposes.

Recently, high estimates show that only 15 Mha of land is under cultivation and over 3.73 Mha of farmlands could potentially develop by irrigation (Makombe et al., 2011). Even though the irrigation potential of the country has been estimated to be about 3.73 million hectares, only 626,116ha (5.6% of the potential) is currently under irrigation and the GTP is planned to develop 15.4% of the capacity at the end of 2015 and it will boost the irrigable land to 1,721,819 ha. This plays an insignificant role in the country's agricultural production (Hagosa et al., 2009, MoWE, 2013).

In the study area, there is an apparent lack of land resource management, and its agricultural system does not yet fully utilized. These direct results from no systematic land suitability assessment and matching of the crop water requirement of the land. So far there has been no study done in this area concerning irrigation potential assessment. Therefore, the main objective of this study was to properly assess the irrigation potential of the watershed.

## Materials and Methods

### *Description of the study watershed*

The study was conducted at Shaya watershed of Bale zone, Oromia regional state which lies between $6^0$ 52' - $7^0$ 15'N latitudes and $39^0$ 46'- $40^0$ 02 E longitude. The catchment situated in the Genale - Dawa basin at the uppermost portions of the Web sub-basin, which is one of the sub-basins of the Genale - Dawa basin. It covers a total drainage area of 32221km$^2$ and with a mean annual rainfall of 1123.2mm. In study watershed, high rainfall was recorded in months, May to September whereas the lower rainfall was recorded in months, October to April in all stations.

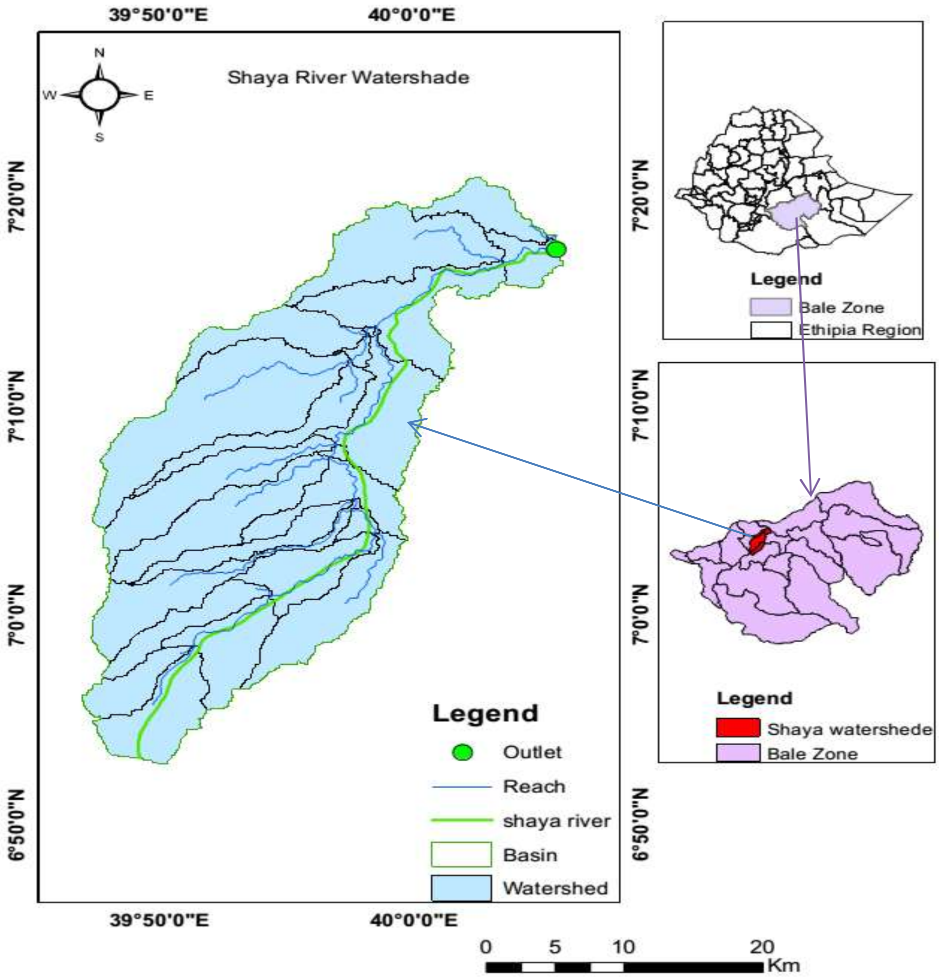


Figure 1. Location map of the study area.

***Data collection and analysis***

*Climate data*

The required Meteorological data's such as precipitation, maximum and minimum air temperature, sunshine hours, wind speed and relative humidity collected from National Meteorological Service Agency (NMSA) of Ethiopia used as data input in CROPWAT 8 software to calculate Reference Evapotranspiration, Irrigation water requirement (IWR), Net irrigation water requirement (NIWR and Gross irrigation water requirement (GIWR).

**Reference Evapotranspiration ($ET_o$):** it was calculated from climatic data using the FAO Penman-Monteith method (Table 1).

**Crop evapotranspiration (ETc):** the crop evapotranspiration (ETc) is the crop water requirement (CWR) for a given cropping pattern during a certain period. Crop evapotranspiration was calculated by multiplying the kc values at each growth stage of the specific crop by the corresponding ETo values (FAO, 2002).

$$ET_c = ET_o * K_c$$

where:

| | | |
|---|---|---|
| ETc | = | Crop evapotranspiration (mm/day) |
| ETo | = | Reference crop evapotranspiration (mm/day) |
| Kc | = | Crop coefficient (fraction) |

**Irrigation water requirement (IWR):** using the climate, rainfall, crop and soil data inputs crop water requirement and irrigation water requirement of each crop was calculated by the following expression in CROPWAT 8.0 software.

$$ET_c = ET_o - pef$$

where:

| | | |
|---|---|---|
| IWR | = | Irrigation water requirement (mm) |
| Pef | = | Effective rainfall (mm) |
| ETc | = | Crop evapo-transpiration for a given crop (mm/day) |

Table 1. Climatic data of the study area.

| Month | Min Tem °C | Max Tem °C | Humidity % | Wind km/day | Sun Hours | Rad MJ/m²/day | ETo mm/day |
|---|---|---|---|---|---|---|---|
| January | 6.1 | 22.7 | 54 | 51 | 9.2 | 21.5 | 3.53 |
| February | 7 | 23.6 | 49 | 51 | 9.3 | 22.8 | 3.89 |
| March | 8.3 | 23.3 | 52 | 60 | 8.3 | 22.2 | 3.99 |
| April | 9.7 | 22.7 | 65 | 51 | 7.2 | 20.6 | 3.73 |
| May | 9.5 | 22.1 | 70 | 60 | 7.7 | 20.7 | 3.69 |
| June | 9.1 | 22.8 | 67 | 69 | 6.3 | 18.2 | 3.41 |
| August | 8.9 | 21.3 | 64 | 51 | 5.3 | 17.3 | 3.21 |
| September | 8.9 | 20.9 | 64 | 69 | 6.6 | 19.5 | 3.53 |
| October | 8.6 | 19.7 | 67 | 51 | 7.7 | 20.6 | 3.47 |
| November | 6.5 | 20.5 | 63 | 43 | 9.2 | 21.7 | 3.45 |
| December | 5.9 | 21.6 | 58 | 51 | 9.2 | 21 | 3.37 |
| Average | 8.1 | 21.9 | 61 | 56 | 7.5 | 20.1 | 3.53 |

**Net irrigation water requirement (NIWR)**: the sum individual crop water requirements (CWR) calculated for each irrigated crop (FAO, 2002)

$$NIWR = \frac{\sum_{n=1}^{n} IWRi * Ai}{A}$$

where:

| | | |
|---|---|---|
| NIWR | = | Net irrigation water requirement (mm) |
| Ai | = | The area cultivated with the crop i (ha) |
| A | = | The area of the scheme (ha) |

**Gross irrigation water requirement (GIWR)**: GIWR of the five crops were estimated and found less than that the available mean monthly flows of Shaya River at their corresponding command area. According to (FAO, 2001) GIWR of crops at the identified potential irrigable site was estimated by considering application efficiency of 50% for surface irrigation.

$$GIWR = \frac{NIWR}{Ea}$$

where :

| | | |
|---|---|---|
| Ea | = | Water application efficiency (%) |
| GIWR | = | Gross irrigation requirements (mm) |
| NIWR | = | Net irrigation water requirement (mm) |

*Slope suitability analysis*

Analyzing slope is important for soil formation and management because of its influence on runoff, drainage, erosion, and selection of methods of irrigation. To derive slope suitability the watershed, digital elevation model of the area clipped from SRTM of NASA satellite with a 30m resolution by masking layer of Shaya river basin, then the slope map of sub-catchment was derived using the "Spatial Analysis Slope" tool in ArcGIS. The four suitability ranges or slope suitability criteria (S1= 0 - 2%, S2= 2 - 5%, S3= 5-8% and N >8%) classified for surface irrigation (FAO, 1997).

*Soil suitability analysis*

To assess soil suitability for irrigation, soils in the study watershed classified from the revised FAO/UNESCO-soil map of East Africa (1997) classification system is used as a reference. Soil types, soil depth, soil drainage and soil texture in the basin then reclassified, Physical properties of these soil groups used for irrigation suitability analysis. Soil suitability rating was used based on FAO guidelines for land and water bulletin (FAO, 1997).

***Soil texture***: according to (FAO, 1999) guidelines for soil elevation, the soil texture of the study area was evaluated and classified into clay, loam, clay loam, Silty loam and sandy loam.

*Land use/land cover analysis*

A land-use and land-cover map of the study area extracted from the 1:250,000 scale of the land use /land cover map developed by the Ethiopian mapping agency. Land use/ cover types of the study area were ranked based on their suitability for irrigation potential, working efficiency, costs to land clearing or land preparing for cultivation and environmental impacts. Samples for water quality analysis were collected from sources used for irrigation; namely, the Shaya river. The water sample was analyzed for pH and ECw to ensure the suitability of water for irrigation Potentially irrigable land was identified based on the specified suitable criteria by creating irrigation suitability model analysis which involved weighting of values of all suitability factors like soil texture, drainage, depth, slope, land use/cover.

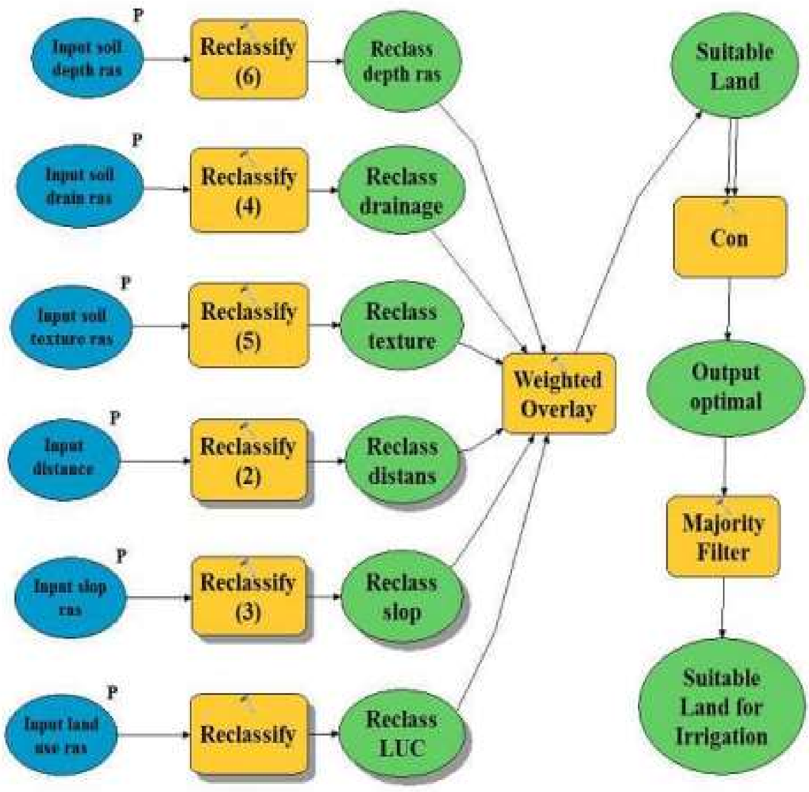


Figure 2. Irrigation suitability model.

Table 2: Soil suitability factor rating for irrigation suitability.

| Factors | Factor Rrating | | | |
|---|---|---|---|---|
| | S1 | S2 | S3 | N |
| Drainage class | Well | Imperfect | Poor | Very poor |
| Soil depth(cm) | >200 | 100-140 | 50-100 | <50 |
| Soil texture | L-SiCL, C | SiL,SCL | SL | Si-L |
| Salinity | <4mmhos/cm | 4-8 mmhos/cm | 8-16 mmhos/cm | > 16 mmhos/cm |
| Alkalinity | <15 ESP | 15-30 ESP | 30-35 ESP | >35 ESP |
| Organic Carbon(OC)% | >10% | 2-10% | - | <2% |
| Acidity and Alkalinity (pH) | 5.5-7.0 | 5.5-4.5,7.0-8.5 | 4 -4.5 , 8.5-9.5 | <4.0 ,>9.5 |
| Capacity(CEC) meq/100 g soil | 35-70 | 35-16 | | <16 |

Source: FAO guideline for land evaluation (1976, 1979 and 1991), (Narayana Swamy et al., 2017).

Table 3. Soil characteristics, limits and degree of suitability for surface irrigation.

| Soil characteristics | Suitability | | | |
|---|---|---|---|---|
| | High (S1) | Moderate (S2) | Marginal (S3) | Unsuitable (N) |
| ESP (%) | <10 (PH<8.5) | 10 - 15 (PH>8.5) | 15 -30 (PH 8.5-9) | >30 (PH>9) |
| Topsoil Stoniness Vol. (%) | 3-5 (fine gravel) | 15 – 40 | 40 -75 | > 75 |
| Subsoil stoniness Vol. (%) | < 10 | 15 - 40 | 40 -75 | >75 |

Source: Dent and Young (1981).

Table 4. Analysis of soil suitability.

| No | Soil Type | Texture | Depth (cm) | Drainage | Texture Suit. | Depth Suit. | Drain Suit. | Soil Suit. | Area | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | ha | % |
| 1 | Haplic Luvisol | SL | 200 | Well | S3 | S1 | S1 | S3 | 94,228.46 | 29.25 |
| 2 | Vertic Luvisol | C | 200 | Moderate | S1 | S1 | S2 | S1 | 82,246.41 | 25.53 |
| 3 | Eutric Cambisol | L | 100 | Well | S1 | S3 | S1 | S1 | 70,238.86 | 21.49 |
| 4 | Chromic Cambisol | CL | 100 | Moderate | S2 | S3 | S2 | S2 | 42,161.80 | 13.08 |
| 5 | Dystric Cambisol | L | 140 | Well | S1 | S2 | S1 | S1 | 30,100.09 | 9.34 |
| 6 | Eutric Regosol | Si-L | 50 | Well | N | N | S1 | N | 4,179.86 | 1.31 |

## Results and Discussion

### *Slope suitability evaluation*

Resulted from slope analysis in ArcGIS, the slope of the study areas classified into four suitability classes (S1, S2, S3, and N) based on the (FAO, 1999) suitability classes and the final slope suitability map developed as shown in Figure 3. The slope analysis indicates that about 66.38% (covering an area of 213,854.66 ha) of the watershed was covered with less than 8% slope class where this land classified under highly suitable to marginally suitable for surface irrigation. Only 33.62% (covering an area of 108,281.33 ha), of the sub-basin area having a slope of greater than 8%, which is permanently not suitable for irrigation. According to (FAO, 1999) suitability classification for surface irrigation, most of the area of the Shaya river basin was found to be suitable for surface irrigation regarding its work efficiency and cost for land leveling, canal construction, and value for the pumping system.

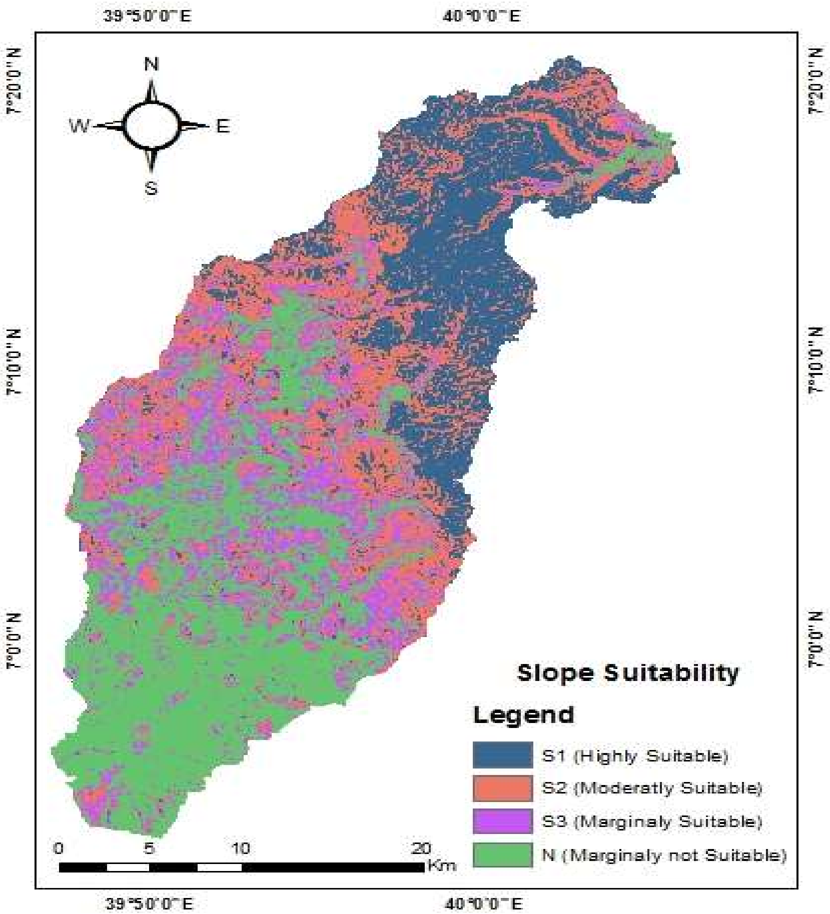


Figure 3. Reclassified slope suitability map.

***Soil suitability evaluation***

There are three major soil groups in the Shaya river watershed, the Cambisol, luvisol, and Regosol of which again classified into six soil units, the Dystric Cambisols, Eutric Cambisols, Chromic Cambisols, Haplic Luvisols, and Eutric Regosols. The final evaluated of Soil suitability for irrigation indicating soil texture, depth, and drainage after reclassification obtained for the watershed Soil types were having soil texture clay to clay loam, soil depth greater than 2m and the excellent soil drainage classified as highly suitable (S1). It covered 182,594.91ha, (56.68%) of the total area coverage of the study area. The second suitability class is moderately suitable classes (S2). It covered the third extent of the area as 42,158.61ha, (13.08%) in the study area and is comprised of soil type having soil texture clay loam, with a soil depth of 1.4 to 1m, and moderate soil drainage. Their reasonable drainage condition limits these soil types while the other factors are optimum for surface irrigation. Soil types having silty loam and heavy clay soil texture, with a soil depth of 50 cm having moderate soil drainage was classified as N (marginally not suitable), and it covered 4,179.86ha (1.31%) of the total area coverage of the study area. They were limited by shallow soil depth (Eutric Regosol) while other factors were optimum for surface irrigation. In general, majority soils of the Shaya river watershed were found to be suitable for surface irrigation.

***Land use/cover evaluation***

Seven primary land-use and land-cover classes were recognized. Land use/ cover types of the study area were ranked based on their suitability for irrigation potential, working efficiency, costs to land clearing or land preparing for cultivation and environmental impacts. Land use/cover classes of cultivated land were classified as highly suitable for irrigation with the assumption that these land cover classes could spray without or with the limited cost for land clearing and farm preparation. It covered 68.03% of the study area. According to the agricultural practice, a commonly grown grassland area classified as the second suitable area next to cultivation.

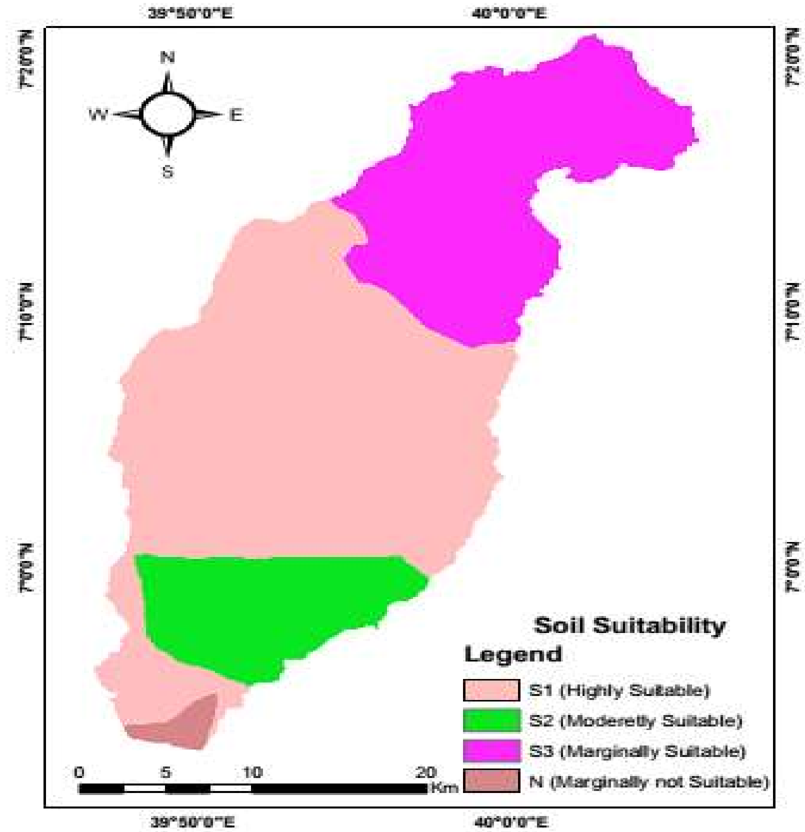


Figure 4. Reclassified soil type of the study area.

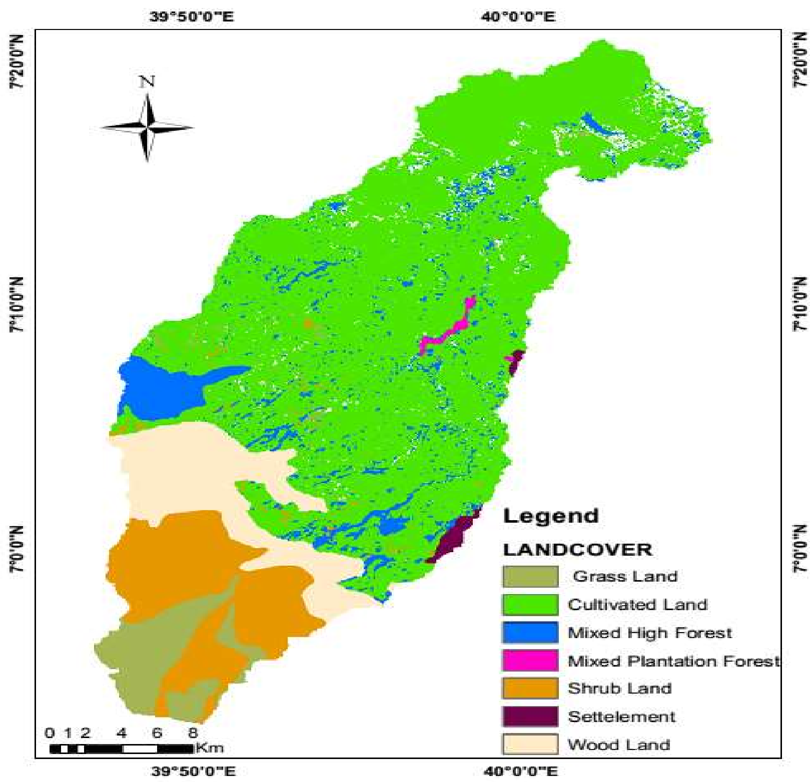


Figure 5. Reclassified land use land cover map of the study area.

On the land use/cover suitability classification, wood and shrubland classified as lands marginally suitable for irrigation. These are due to their work efficiency, the cost for land clearing and land preparation for spraying, whereas dense forest, residence were classified as lands not suitable for irrigation. Those land cover classes were 7.07% of the total land cover of the study area they are restricted to use for irrigation. The measured pH values of water samples varied from 6.92 to 7.35 (from near neutrality to slightly basic in reaction). ECW values of irrigation water samples varied from 0.488 ds/m to 0.657 ds/m. the slight restriction value of pH is greater than 7.5 and less than 6.5. The slight restriction values of ECW are greater than 0.7 ds/m. The measured pH and ECW values are in all normal ranges and suitable for irrigation.

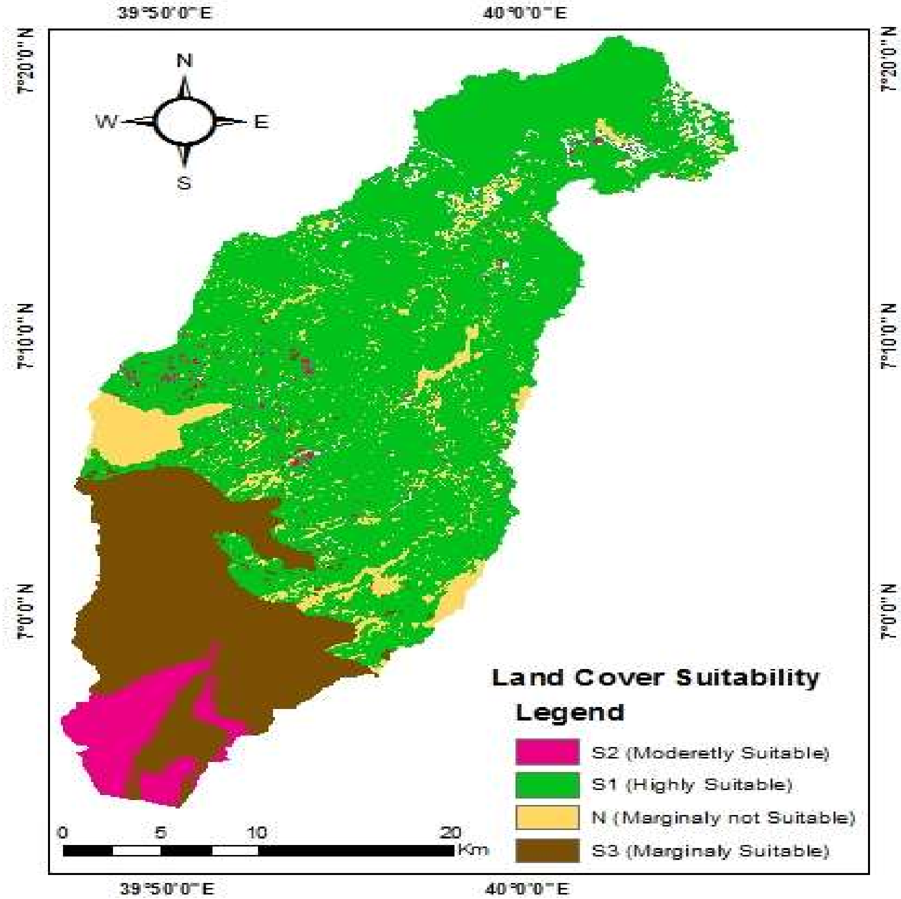


Figure 6. Land cover suitability map of the study areas.

***Suitable land for irrigation***

Potentially irrigable land was identified based on the specified suitable criteria by creating irrigation suitability model analysis which involved weighting of values of all data sets such as soil texture, drainage, depth, slope, land use/cover. From the total area coverage of the study area 22.05% (71,046.03ha) was classified as high suitable (S1), 25.27% (81,420.45ha) moderately suitable (S2), 16.20% (52,187.67ha) marginally suitable (S3), whereas 33.57% (108,168ha) not suitable (N) for surface irrigation (Figure 7).

***Irrigation potential of river sub-basin***

After an evaluation of the suitability land of irrigation, it is essential to examine the irrigation water availability for crops produced in the study area. Irrigation potential of the river sub-basin obtained by comparing irrigation water demand of the five crops commonly grown in the study area, in considering the identified suitable land for irrigation and the 90% steady, monthly flows of the Shaya River (Table 5). The results of these analyses revealed that the available monthly flow of the river was higher than the irrigation water requirements of all crops at their corresponding command area.

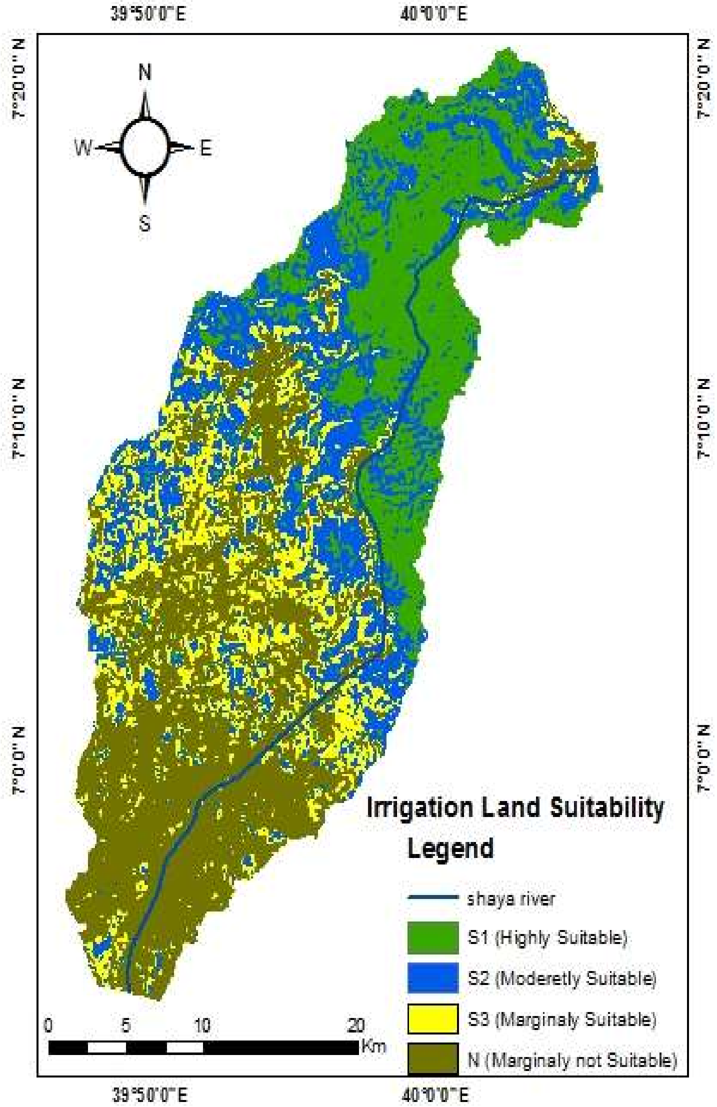


Figure 7. Irrigation land suitability map of the study.

Table 5. Irrigation demands and available river flow in the study area.

| Month | GWR ($m^3$/S) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Potato | Tomato | Onion | Maize | Pepper | Sum of GIR | 90% Probability flow |
| Jan | 4.3 | 4.93 | 0.36 | 0 | 4.4 | 13.99 | 18.57 |
| Feb | 0.74 | 2.94 | 0 | 0 | 0.22 | 3.9 | 12.25 |
| Mar | 0 | 0 | 0 | 0 | 0 | 0 | 8.52 |
| Apr | 0 | 0 | 0 | 0 | 0 | 0 | 10.53 |
| May | 0 | 0 | 0 | 0.9 | 0 | 0.9 | 11.27 |
| Jun | 0 | 0 | 0 | 1.9 | 0 | 1.9 | 11.20 |
| Jul | 0 | 0 | 0 | 0.71 | 0 | 0.71 | 10.45 |
| Aug | 0 | 0 | 0 | 1.42 | 0 | 1.42 | 12.81 |
| Sep | 0 | 0 | 0 | 0.1 | 0 | 0;1 | 10.53 |
| Oct | 2.06 | 2.39 | 2.01 | 0 | 1.05 | 7.51 | 12.22 |
| Nov | 2.16 | 1.64 | 2.27 | 0 | 1.6 | 7.67 | 20.35 |
| Dec | 3.88 | 3.82 | 3.45 | 0 | 3.45 | 14.6 | 19.31 |

## Conclusion

The overall result indicates that most of the Shaya River sub-basin was potentially suitable for irrigation development. From results obtained the conclusion that could draw was all most above half of the watershed area was potentially suitable for irrigation (63.52 percent of the watershed) concerning slope, soil and land use/cover. As comparing gross monthly irrigation demand of identified irrigable land under river sub-basin with corresponding 90% available monthly river flows, the river potential is higher in all months so that the river is potentially adequate to spray the water without storage provided.

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