Assessment of Irrigation Potential in Jewuha Watershed, Middle Awash River Basin, Ethiopia

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Assessment of Irrigation Potential in Jewuha Watershed, Middle Awash River Basin, Ethiopia

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ABSTRACT

Ethiopia is endowed with immense water and land resources that could be tapped and used for irrigation development. However, little has been done so far due mainly to lack of comprehensive knowledge on the potential of these resources. This study was, therefore, taken up to assess the irrigation potential in data scarce Jewuha watershed of the Awash River Basin. To achieve the objective of the study, the suitability of the land for both surface and pressurized irrigations was estimated using a parametric evaluation technique combined with the FAO land evaluation framework in the GIS environment with multi-criteria analysis of irrigation suitability factors. The irrigation water demands of major crops adopted in the area were determined using CROPWAT software. The surface water potential at the sub watershed was estimated using a combination of SWAT model and the spatial proximity regionalization technique. The performance of the SWAT model was checked by statistical parameters. The irrigation suitability analysis reveals that 51372ha of the study area are suitable and 16274ha are unsuitable for surface irrigation system. Furthermore, 52768ha of the area are suitable and 15088ha are unsuitable for a sprinkler irrigation system. For drip irrigation, 52751ha are suitable and 14855ha are unsuitable. The calibration and validation of SWAT model showed that the model has performed well to simulate the hydrology of the watershed with a coefficient of determination (R^2), Nash-Sutcliffe efficiency (NSE) and Percent of bias (PBIAS) of 0.74, 0.73 and 0.80 for calibration and 0.71, 0.70 and 7.90 for validation, respectively. From a combined analysis of the available land and water resources, the gross irrigation potential of the area is estimated to be 12,997ha, of which 3098ha of land is exclusively suitable for surface irrigation and 9,899ha is suitable for pressurized irrigation systems.

Key words: Land suitability, SWAT, GIS, CROPWAT, Irrigation potential

1 Introduction

Over 85 percent of Ethiopia's population lives in rural areas and relies on agriculture for subsistence (Awulachew et al. 2007). The country has huge water resource potential that comprises 12 river basins with an annual runoff volume of 124 billion m^3 of water and over 2.6 billion m^3 of groundwater potential (Melesse et al. 2014; Worku Ayalew 2018). But there is not sufficient water for most farmers to produce more than one crop per year due to a lack of water storage structures and large spatial and temporal variations in rainfall. Therefore, irrigation development and improved agricultural water management practices could provide opportunities to cope with the impact of climatic variability, enhance productivity per unit of land, and increase the annual crop production volume significantly(Awulachew and Merrey 2005).

Ethiopia also has a total cultivable land of between 30 to 70 million hectares out of 112 million hectares, but only 15 million hectares of land is under cultivation. However, only about 4% of this cultivated area has been irrigated so far (Awlachew et al. 2010), despite the fact that there is no precise figure for the potential and actual irrigated area. This is due to a lack of consistent, reliable inventory, well-studied and documented data. Also, this shows that there is a lack of detailed studies in the area. So, assessment of irrigation potential for irrigation development is important to utilize the land resources efficiently for the sustainable production of crops and to sustain the food security of the rapidly increasing population in the country (Haile 2015). Among the 12 river basins in Ethiopia, the Awash river basin is one of them, covering a total area of 110,000km^2. The Awash river basin is the most intensively utilized river basin for irrigation development in Ethiopia due to its strategic location, accessibility, available land, and water resources (Awash Basin Authority 2017). However, the most utilized part is the upper part of the basin and relative to the total area, there is very little area to be utilized. Due to this, assessing irrigation potential in the Awash River basin is needed for more effective use of the basin for agricultural development.

Irrigation development could improve agricultural productivity and enhance socio-economic development through the growth of production (AU 2020). But most of Ethiopia, particularly in the study area, practiced traditional agricultural activity. This shows that irrigation development in the study area is necessary and to do this, first the potential site for irrigation must be identified. Therefore, the objective of this study is to assess the irrigation potential for different irrigation systems in the Jewuha watershed to easily develop an irrigation project and the surface water resource potential is assessed using the SWAT model (Arnold et al. 2012). Furthermore, the irrigation water demand of the major crops adopted in the study area was estimated using the CROPWAT model (FAO 1992).

2 Materials and Methods

2.1 Description of the study area

Jewuha watershed is located in the Awash river basin. It is geographically located between 39°44'55" to 40°10'4"E and 10°00'3" to 10°21'10"N. The watershed is 240km away from the capital city Addis Ababa in the northeast direction.

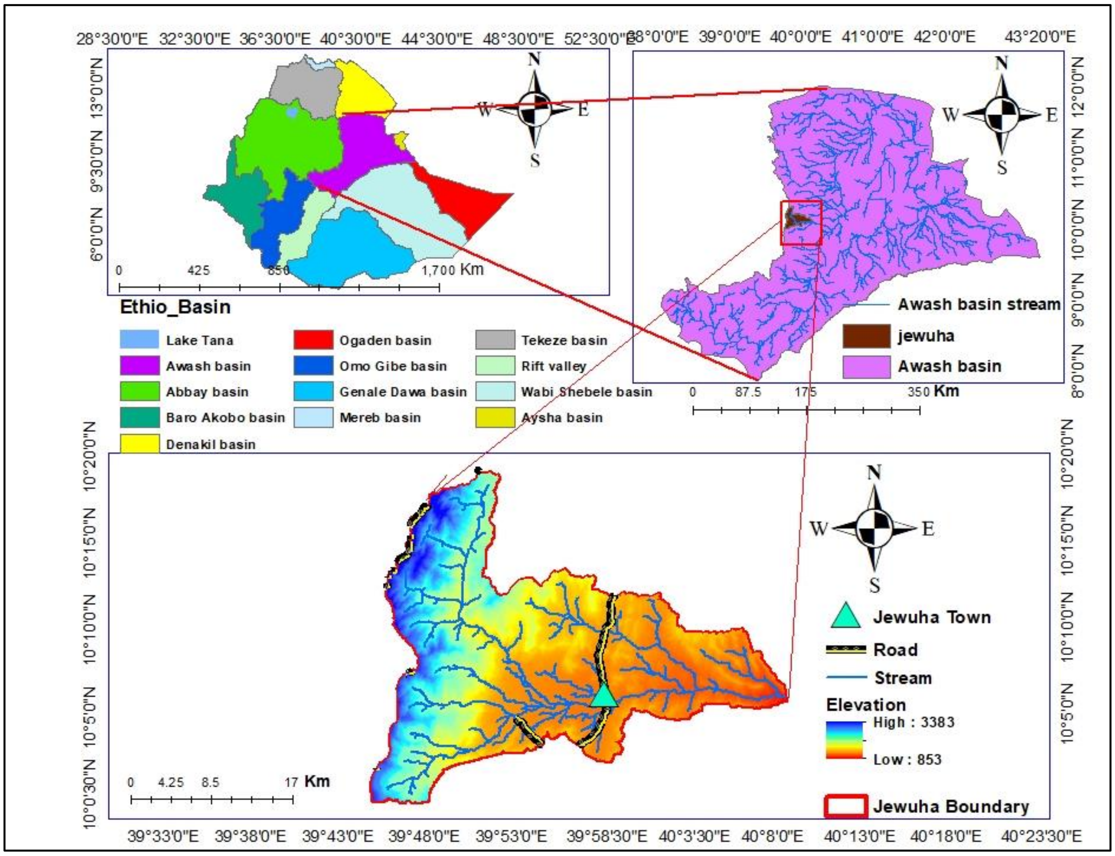


Fig.2.1 Location of the study area

The topography of the Jewuha watershed is characterized by diverse topographic conditions. The upper part of the watershed is characterized by mountainous and highly separated terrain with steep slopes and the downstream part is a gentle slope that is suitable for agricultural activity, with elevation ranges from 3555m in the mountainous area to 1101m in the lowland. The general topography of the catchments is undulating hills and flats.

The climate of the Jewuha watershed is characterized by high rainfall with low temperatures in the highland and low rainfall with high temperatures in the low land area. According to the Ethiopian agro-climatic zone classification, the climate of the study area ranges from hot temperate (Kola) around the low land of the Jewuha town area to cool temperature (wurch) in the mountains and escarpment.

Rainfall distribution over the area is bimodal, characterized by a short rainy season (Belg) that occurs between March and April and a long rainy season (kiremt) that occurs between June and August, with a dry season from December to February. In the dry season, the rainfall ranges between 218 and 259mm, whereas in the wet season it ranges between 600mm to 1500mm.

The temperature in the study area is hot in the low land areas, reaching up to 34.4°C and the lowest temperature is recorded at Molale station on the highland, reaching up to 7°C and sometimes it is less than this value.

The land use land cover map gives the spatial distribution and classification of the various land use land cover classes. Different land cover types have been found in the study area in terms of areal coverage. The important land cover units are forest, shrubs, grassland, intensively cultivated, woodland, bare areas, and built-up areas.

The types of soil found in the study area are Eutric Fluvisols, Vetric Cambisols, Leptosols, Eutric Cambisols, Chromic Cambisols, Chromic Vertisols, Haplic Xerosols, Eutric Regosols and Cambic Arenosols.

2.2 Data Types and Source

To achieve the objectives of the study, different data inputs were collected from various sources and field observations.

2.2.1 Metrological data

Metrological data were collected from the National Metrological Agency of Ethiopia (NMAE). Shewa Robit and Majeta climate stations were used for WGEN statistics calculation for SWAT using SWAT Weather database. The SWAT Weather Database (Essenfelder 2018) is designed to be a friendly tool to store and process daily weather data to be used with SWAT projects. It is capable of storing relevant daily weather information, easily generating.txt files that are used for input during SWAT project and efficiently calculating the WGEN statistics from one or more gauge stations. The daily weather data such as relative humidity (HMD), precipitation (PCP), solar radiation (SLR), maximum and minimum temperature (TMP), wind speed (WND) and the batch file containing the location of the gauge stations are loaded to SWAT Weather Database to calculate the WGEN statistics. The continuity and consistency of the meteorological data were checked by the normal ratio method and double mass curve, respectively.

2.2.2 Hydrological data

The daily stream flow data of (1985-2003) at Jewuha, 1988-2001 at Ataye, and 1995 – 2011 at Robi gauging station were collected from the Ministry of Water, Irrigation and Energy (MoWIE). Ataye and Robi river were used for validation of the regionalization technique in model parameter transfer for the ungauged sub wateshed.

2.2.3 Spatial data

The data which is considered as spatial data includes DEM, land use land cover, soil map, and road map. Digital elevation model (DEM) was obtained from the USGS website. The soil chemical parameters of CaCO3 and EC covering the study area were obtained from the Harmonized World Soil Database (HWSD) on the FAO website, in Environmental System Research Institute (ESRI) shape file format and Micro Soft Access database (Nachtergaele et al. 2009) and soil physical properties were obtained from the map of the Awash river master plan soil survey study from the GIS and remote sensing department in the Awash basin authority, Adama branch.

Land use land covers were obtained from the Water and Land Resource Center (WLRC), Addis Ababa; Ethiopia. The road map is another spatial data set that is used to extract road proximity to assess the irrigation potential of the study area and it is obtained from the DIVA-GIS website.

2.3 Land suitability

Land suitability assessment means evaluating the parcel of land for irrigation or agricultural development (FAO 1976). Soil physical and chemical properties and topography, a characteristic of the land includes soil depth, texture, drainage, slope, CaCO3, EC and slope were taken to assess the suitability of the land in the study area. The digital soil map was prepared and obtained from different organizations, then analyzed in a GIS environment. The soil characteristics that were considered for land suitability assessment were taken from different works of literature (M.Albaji et al. 2008; Sys et al. 1991; Worqlul et al. 2015; Kassaye et al. 2019; Mandal et al. 2018).

Among the different land suitability assessment techniques, this study was interested in parametric evaluation systems prepared by (Sys et al. 1991) based on the soil characteristics. Parametric procedures usually allocate numerical ratings to separate land characteristics or land qualities depending on their relevance to the land use considerations. Then, they are combined into one numerical result using a mathematical equation as shown. These soil characteristics are rated and used to calculate the capability index (CI). The rating table was obtained from the tables prepared by (Sys et al. 1991).

$$CI = A \times \frac{B}{100} \times \frac{C}{100} \times \frac{D}{100} \times \frac{E}{100} \times \frac{F}{100} \qquad (1)$$

Where CI is the Capability index for irrigation, A= soil texture rating, B = soil depth rating, C = CaCO3 rating, D = EC rating, E = drainage rating, F = slope rating

Table 1 Capability indices (CI) class for land suitability

Capability index	Definition	Symbol
>80	Highly suitable	S1
60 - 80	Moderately suitable	S2
45 - 59	Marginally suitable	S3
30 - 44	Currently not suitable	N1
<29	Permanently not suitable	N2

2.4 SWAT Model Description

The water availability in the study area was assessed using the SWAT hydrological model. SWAT (Arnold et al. 2002) can simulate hydrological cycles, vegetation growth, and nutrient cycling with a daily time step by disaggregating a river basin into sub-basins and hydrologic response units (HRUs). SWAT uses the following water balance equation to simulate the hydrologic cycle within a watershed.

$$SW_t = SW_o + \sum_{i=1}^{n} (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \qquad (2)$$

Where; SW_t is the final water content (mm H_2O), SW_o is the initial soil water content on the day i (mm H2O), t is time, days, Rday is the amount of precipitation on the day i (mm H2O), Qsurf is the amount of surface runoff on the day i (mm H2O), Ea is the actual evapotranspiration on the day i (mm H2O), Wseep is the amount of water entering the vadose (unsaturated) zone from the soil profile on the day i (mm H_2O), Q_{gw} is the amount of return flow on the day i (mm H_2O).

The model reflects the difference in evapotranspiration for various land use and soil type in the subdivision of watersheds. The runoff was predicted separated from each HRU and routed to obtain the total yield for the watershed. Hence, increase the accuracy and gives a better physical description of water balance.

2.4.1 Sensitivity analysis

Sensitivity analysis is the way of determining the rate of change in model results concerning changes in model parameters (Abbaspour 2012). Sensitivity analysis is important to provide information on the most important parameters that affect the process in the study area and helps to decrease the number of parameters in the calibration procedure by eliminating the parameters identified as not sensitive (Abbaspour et al. 2017).The sensitivity of the parameter was selected based on the P-test and t-test values. The value that has a high P and a low t value is the most sensitive parameter. The SUFI-2 (Sequential Uncertainty Fitting 2) program which is linked to SWAT-CUP (Abbaspour 2012) was used for a combined model sensitivity and uncertainty analysis, calibration, and validation procedures. From the two sensitivity analysis techniques in SWAT-CUP; global sensitivity analysis technique was used.

2.4.2 Model Calibration and Validation

Calibration is an effort to better parameterize a model to a given set of local conditions, thereby reducing the prediction uncertainty (Abbaspour et al. 2017). The prediction of uncertainty of SWAT model calibration and validation results was analyzed by the SWAT calibration uncertainties program known as SWAT-CUP (Abbaspour 2012). It is a public domain program that links Sequential Uncertainty Fitting (SUFI-2) (Abbaspour et al. 2007), Particle Swarm Optimization (PSO) and Parameter Solution (ParaSol) (Beven and Binley 1992) and Marko Chain Monte Carlo (MCMC). For this study, SUFI-2 was used for calibration of the model. To show the intimate relationship between the simulation result, expressed as 95PPU, and the observation expressed as a single signal (with some error associated with it), two statistics values are used (Abbaspour et al. 2007). These are the p-factor and r-factor, which give a good measure of the strength of calibration results. The P-factor is the percentage of measured data bracketed by the 95PPU band and the r-factor is a measure of the thickness of the 95PPU. The value of the p-factor and R-factor is between 0 and 1, and 0 to infinity, respectively. A p-factor of 1 and R-factor of 0 indicate simulations are exactly corresponding to the observed data (Abbaspour 2012).

$$r\,factor = \frac{\frac{1}{n}\sum_{t=1}^{n}\left(Q_t^{s,97.5\%} - Q_t^{s,2.5\%}\right)}{\sigma_{obs}} \qquad (3)$$

Where $Q_{ti}^{s,97.5\%}$ and $Q_{ti}^{s,2.5\%}$ are the upper and lower boundary of the 95PPU at time t and simulation i, respectively, nj is the number of data points and σ_{obsj} is the standard deviation of the *jth* observed variable

Model validation is the process of describing that a given site-specific model is capable of making satisfactory simulations. It is the comparison of model results with an independent data set without further adjustment of the model parameters. Validation embraces running a model using parameters that were estimated during the calibration process and comparing the predictions to observed data not used in the calibration process. The hydrological data of Jewuha River from 1990 – 1997 and 1998 – 2003 was used for the calibration and validation of the SWAT model, respectively.

2.4.3 Model performance evaluation

Herein, the performance of the model was checked by statistical tests that can be used to judge the SWAT model. For this study, Nash Sutcliffe efficiency (NSE), percent bias (PBIAS), and coefficient of determination (R^2) were used as recommended by (Moriasi et al. 2007). The coefficient of determination (R^2) describes the proportion of the variance in the measured data explained by the model. R^2 ranges from 0 to 1, with higher values indicating less error variance, and typically, values greater than 0.5 are considered acceptable (Moriasi et al. 2007).

Percent bias (PBIAS) measures the average tendency of the simulated data to be higher or smaller than its observed values. The optimal value of PBIAS is 0.0, with lower magnitude values indicating an exact model simulation. The negative value of PBIAS indicates the models overestimate the simulated and the positive shows the model underestimates the simulated flow (Moriasi et al. 2007).

$$NSE = 1 - \left[\frac{\sum_{i=1}^{N} \left(O_i - P_i \right)^2}{\sum_{i=1}^{N} \left(O_i - \overline{O}_i \right)^2} \right] \tag{4}$$

$$PBIAS = \left[\frac{\sum_{i=1}^{N} \left(O_i - P_i \right) x100}{\sum_{i=1}^{N} O_i} \right] \tag{5}$$

$$R^2 = \left[\frac{\sum_{i=1}^{N} \left(O_i - \overline{O} \right)\left(P_i - \overline{P} \right)}{\sqrt{\sum_{i=1}^{N} \left(O_i - \overline{O}^2 \right)} \sqrt{\sum_{i=1}^{N} \left(P_i - \overline{P} \right)^2}} \right]^2 \tag{6}$$

Where P_i = simulated flow, O_i = observed flow, $\bar{O}_i$= the mean of observed data, $\overline{P}$ is predicted flow and the remaining variable is stated above and N is the total number of observations.

The Nash–Sutcliffe efficiency(NSE) (Sutcliffe 2001) indicating how well the model expresses the variance in the observation. It generally ranges from - ∞ to 1 the optimum value is unity and it shows a good explanation of the observed versus simulated data fits on a one to one line.

Table 2 General performance rating**;** Source:(Moriasi et al. 2007; Arnold et al. 2012)

Performance rating	NS	PBIAS	R^2
Very good	0.75 < NS < 1	PBIAS < ±10%	0.75 < R^2 < 1
Good	0.65 < NS < 0.75	±10% < PBIAS < ±15%	0.65 < R^2 < 0.75

Satisfactory	0.5 < NS < 0.65	±15%< PBIAS < ±25%	0.5 < R^2 < 0.65
Unsatisfactory	NS < 0.5	PBIAS > ±25%	R^2 < 0.5

2.4.4 Regionalization technique for ungauged sub watershed

Regionalization is the process of transferring hydrological information (parameters) of a model from a gauged watershed to an ungauged watershed.

Among the different regionalization techniques, spatial proximity and physical similarity methods are widely used (Oudin et al. 2008; Parajka et al. 2005). In this study, spatial proximity with Inverse Distance Weighting (IDW) was used to transfer the calibrated model parameter of the gauged watershed to the ungauged watershed. And IDW was used to estimate the weight of the ungauged watershed. The distance between the two watersheds was determined using GIS. This regionalization techniques were verified using leave-one-out cross validation, in which a single gauged site is considered as ungauged and the transferred parameters to that site are entered into the SWAT-CUP to validate with the observed flow. Observed flow at Jewuha and the two neighbouring watersheds of Shewa Robit and Ataye gauged watersheds was used to estimate the flow in the ungauged sub-watershed of the Jewuha River. The calibrated parameters of the Jewuha and Robi watersheds were transferred to the other ungauged sub watersheds. The parameters transferred by this technique are added into the SWAT model using a manual calibration helper and then the SWAT model is run to obtain the flow for each sub watershed. The general formula for spatial proximity with the IDW method to regionalize the calibrated parameter of the gauged watershed is as follows.

$$Z_{ug} = \sum_{i=1}^{n} w_i z_i \tag{7}$$

Where Z_{ug} is the estimated model parameter at the ungauged watershed; n is the total number of observed points (gauges); z_i is the calibrated parameter value at gauged watershed and w_i is the weight contributing to the interpolation

$$w_i = \frac{\frac{1}{d_i^2}}{\sum_{i=1}^{n} \frac{1}{d_i^2}} \tag{8}$$

Where d_i is the distance between at the centroids of gauged and ungauged watershed

2.5 Estimation of Irrigation Water Demand

Irrigation water demand is estimated from the water requirement of the crop. The major crops adopted in the study area include maize, cabbage and onion. Several methods and procedures are available to compute the crop water requirement. The computer program available in FAO Irrigation and Drainage Paper No. 56 “CROPWAT”, has been used for the calculation of crop water requirements.

$$ET_C = K_C \times ET_O \tag{9}$$

Where Kc is crop coefficients and ETc is crop evapotranspiration in mm

Irrigation water demand is derived from crop evapotranspiration (ETc) and effective rain fall which is calculated based on USDA soil conservation service. Then the net irrigation water demand of the crop was calculated as follows.

$$NIWD = ET_C - P_{eff} \tag{10}$$

The gross irrigation water demand of the crop has been calculated by considering the loss of water during application of water to the irrigation field, loss in the canal through seepage and evaporation. Thus, so as to compensate for this loss, irrigation efficiency was introduced. The irrigation project efficiency is between 0.45 and 0.7 for surface irrigation and 0.7 to 0.9 for pressurized irrigation systems (Luo et al. 2011). Thus, for this study, average irrigation efficiency was taken as 0.5, 0.75 and 0.85 for surface, sprinkler and pressurized irrigation systems, respectively.

$$GIWD = \frac{NIWD}{\eta} \tag{11}$$

2.6 Irrigation Suitability Area Assessment

The irrigation suitability of the study was assessed by weighing the factors of land suitability, land use land cover, distance from the source, and distance from the road (Nigussie et al. 2019; Rediet et al. 2020; Kasye Shitu 2020).

2.6.1 Land use land cover suitability assessment

The LULC of the study were reclassified based on the classification system of (FAO, 1976) using the reclassification tool, which is an attribute generalization technique in ArcGIS, as highly suitable (S1), moderately suitable (S2), slightly suitable (S3) and not suitable (N).

Table 3 Land use land cover suitability rating; Source:(Rediet et al. 2020; Gurara 2020)

LULC type	Definition	LULC rating (r)	Class
Cultivated land	Highly suitable	4	S1
Grassland/bare land	Moderately suitable	3	S2
Shrub/bush/wood land	Slightly suitable	2	S3
Settlement/forest/wetland	Not suitable	1	N

2.6.2 Distance from the water source (river) suitability assessment

The identification of irrigable land that is close to the water supply (rivers) was done by calculating the straight-line (Euclidean) distance from the streams that is generated from a 20m x 20m cell size DEM in a GIS tool and then reclassifying. The land which is nearest to the stream was considered the most suitable land for irrigation development and the land which is far from the stream is slightly suitable (Birhanu et al. 2019; Worqlul et al. 2015).

The land from the river was reclassified as highly suitable (S1), moderately suitable (S2), slightly suitable (S3) and not suitable (N).

Table 4 Distance from source suitability rating; Source:(Birhanu et al. 2019; Kassaye et al. 2019)

Class	Definition	Rating (r)	Distance from river (Km)
S1	Highly suitable	4	0 – 2
S2	Moderately suitable	3	2 – 4
S3	Slightly suitable	2	4 – 5
N	Not suitable	1	>5

2.6.3 Distance from road suitability assessment

The road maps obtained from the DIVA-GIS website were reclassified based on the classification system of (FAO 1976) using the reclassification tool in the GIS. It is classified as highly suitable (S1), moderately suitable (S2), slightly suitable (S3) and not suitable (N) by ratings of 4, 3, 2, and 1, respectively.

Table 5 Distance from road suitability rating; Source: (Worqlul et al. 2015)

Class	Definition	Rating (r)	Distance from road (Km)
S1	Highly suitable	4	0 – 3
S2	Moderately suitable	3	3 – 5
S3	Slightly suitable	2	5 – 8
N	Not suitable	1	>8

2.6.4 Weighted overlay of irrigation suitability factors

To find an overall suitable site for irrigation, a suitability model was created using the model builder in the GIS Arc tools box to overlay the factor to map the suitable land. The weights developed above for each factor were overlaid in GIS to undertake multi-criteria evaluation (MCE) (Khongnawang and Williams 2015). In a multi-criteria evaluation, an attempt is made to combine a set of criteria to achieve a single composite basis for a decision according to a specific objective. The relative importance/weight of criteria and sub-criteria was estimated using multi-criteria evaluation through AHP, applied by using pairwise comparison of each suitability factor developed by (Saaty 1977).

In pairwise comparison, each factor was matched head-to-head (one to one) with the other and a pairwise or comparison matrix was prepared to express the relative importance. The diagonal elements of the pairwise comparison matrix are assigned the value of unity since the diagonal of the matrix value was obtained by the compared value of itself.

To fill the matrix, ratings were given for all factors on a 9 point continuous scale. For example, if one feels that land suitability is very strongly more important than LULC suitability in determining whether it is suitable for irrigation, one will enter 7 on this scale. However, if the reverse is true, one will give the value of 1/7. The value is given based on expert judgment and related literature reviews.

Table 6 Pairwise comparison matric of factors

Factor	Soil	LULC	Distance from river	Distance from road
Soil	1	2	3	4
LULC	1/2	1	2	3
Distance from river	0.333	0.5	1	2
Distance from road	0.25	0.333	0.5	1
Sum	2.08	3.833	6.5	10

Calculate the normalized decision matrix of the irrigation suitability factor, which is obtained by all the elements in each column are divided by the sum of the columns as shown in the Table 9 below. The normalized value is calculated from the pairwise comparison matrices (Aij).

$$N = \frac{\sum j}{c} \qquad (12)$$

Where N is normalized value, j is the column of the matrix and c is the values of the column of the factors

Table 7 Normalized value of factors

Factor	Soil	LULC	Distance from river	Distance from road
Land	0.48	0.52	0.46	0.4
LULC	0.24	0.26	0.31	0.3
Distance from river	0.16	0.13	0.15	0.2
Distance from road	0.12	0.09	0.08	0.1

The Eigenvectors and weights of the criteria were calculated from the normalized matrix through summation and average of the row values of each element in the row, respectively.

Table 8 Eigenvector value of criteria

Factor	Eigenvectors
Land	1.86
LULC	1.11
Distance from river	0.64
Distance from road	0.39

$$W_i = \frac{\sum N}{x} \qquad (13)$$

Where W_i the weights of the criteria, N is the row values of normalized matrix and x is the number of criteria for suitability analysis.

With a weighted linear combination, factors are combined by applying weight or percent of influence to the suitability of the irrigation obtained by the pairwise comparison technique. The multiplication was based on the following equation.

$$S_i = \sum_{i=1}^{n} W_i X_i \qquad (14)$$

Where S suitability, W_i is the weight of factor, X_i is criteria score of factor available water in the river in volume

The map obtained after overlaying was irrigation suitability, which are classified based on their degree of suitability as highly suitable (S1), moderately suitable (S2), slightly suitable (S3) and not suitable (N) (FAO 1976).

Table 9 Irrigation suitability rating

Suitability rating range	Class	Definition
4	S1	Highly suitable
3	S2	Moderately suitable
2	S3	Slightly suitable
1	N	Not suitable

2.7 Irrigation Potential Area Assessment

Irrigation potential (IP) is the land that is suitable for irrigation and that can be irrigated with the available surface water at a selected diversion site.

Diversion sites are selected by considering different factors. Those includes, diversion site elevation must be larger than the area being irrigated, it should be easily accessed by road, the site should be not be too far from the command area of the project (Dai, 2016) and the river cross section should be straight and narrow.

After the estimation of suitable land, irrigation water demand and available surface water, the actual irrigation potential of the study area was estimated. The actual irrigation potential at the selected diversion site was evaluated using the following formula for each perennial and some intermittent rivers in the watershed.

$$\text{IP(ha)} = \frac{AW}{GIWD} \qquad (15)$$

Where GIWD (m^3/ha) is gross irrigation water demand and AW (m^3) is available water in the river at selected diversion site in m^3/ha or mm (1mm = 10m^3/ha)

The irrigation potential areas which are estimated for each diversion site might not be found along the river and its delineation is difficult. In such case, manual delineation through trial and error was done by following the contour line generated.

3 RESULT AND DISCUSSION

3.1 Land Suitability for Irrigation Potential

The result of land suitability analysis showed that about 12,373ha of land are ranged in between moderately to marginally suitable for surface irrigation, 31,138ha of land are ranged in between highly to marginally suitable for sprinkler irrigation systems and 35,433ha of land are considered highly to marginally suitable for drip irrigation systems.

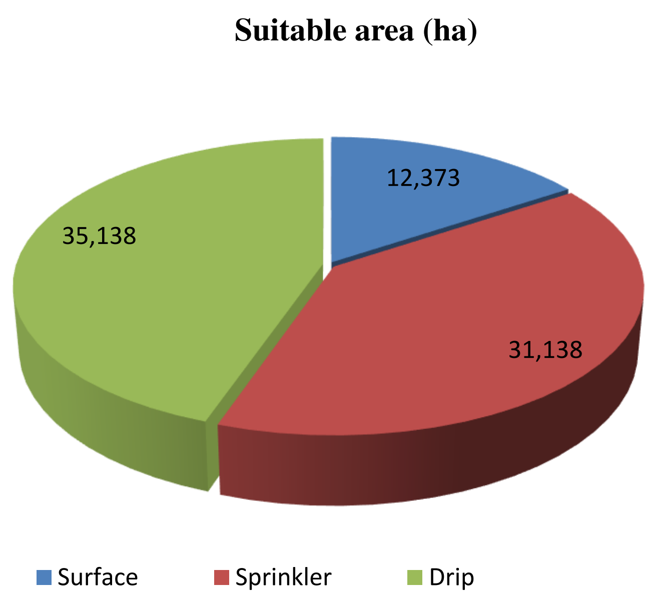


Fig.2 Land suitability chart

3.2 Land use land cover suitability

Based on the(FAO 1976) land suitability classification systems, the land use type was reclassified as 31,492ha highly suitable (S1), 5756ha moderately suitable (S2), 30,599ha marginally/slightly suitable (S3), and 105ha not suitable (N).

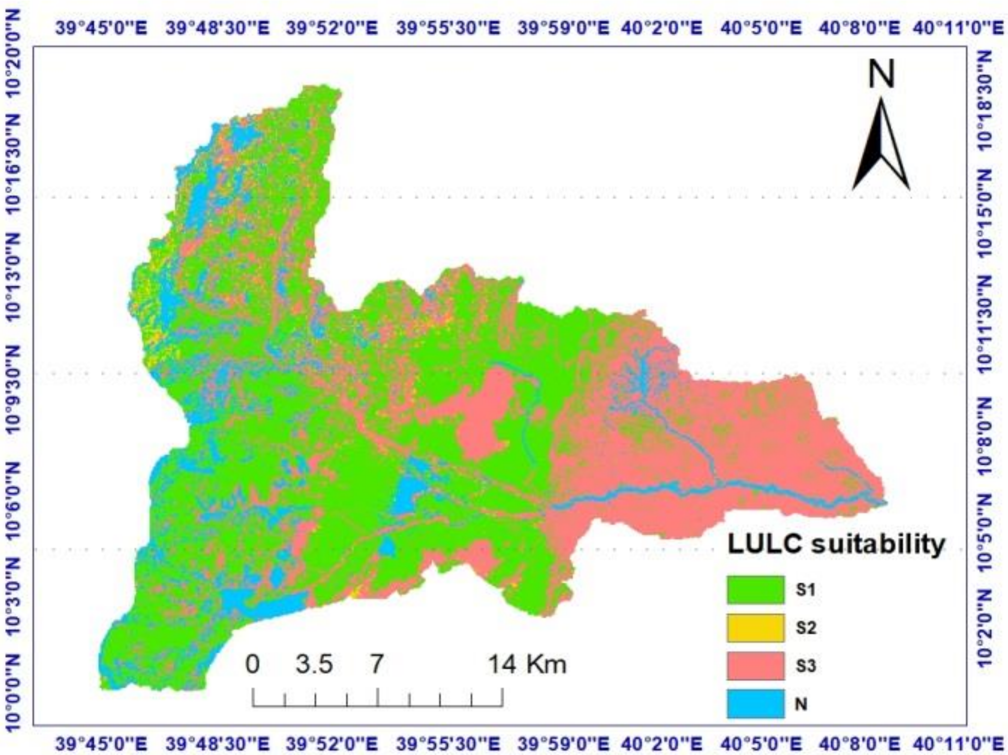
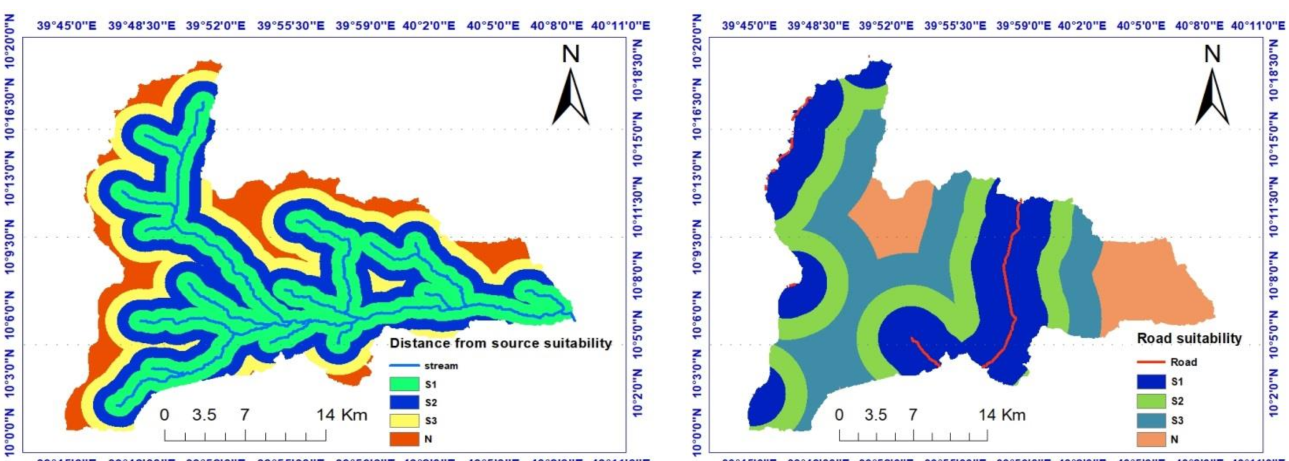


Fig.3 Land use land cover suitability

3.3 Distance from River and Road Suitability

The result of the analysis to estimate the suitability of the land from stream revealed that 27,991ha of land are highly suitable, 18,780ha are moderately suitable 12,412ha of land are slightly suitable and 8779ha are not suitable for irrigation development.

The result of road suitability shows that 21,620ha of land are highly suitable, 17,256ha are moderately suitable, 18,257ha are slightly suitable and 10,830ha are not suitable for irrigation.



a. Distance from source (river) b. Distance from road

Fig.4 Distance from source (river) and road suitability

3.4 Surface water potential

Surface water of the study area was assessed using SWAT hydrological model. The model in the study area can be performed well with good performance.

3.4.1 SWAT model sensitivity Analysis

Among twenty one model parameters that were selected for sensitivity analysis, sixteen parameters were found to be sensitive under the category from high to low sensitive.

The most sensitive parameters of the study area in the SWAT model are R_CN2, ALPHA_BF, R_ESCO, R_EPCO, V_GW_DELAY, V_ALPHA_BF, V_GWQMN, V_GW_REVAP, V_REVAPMN, V_RCHRG_DP, R_SOL_AWC, R_SOL_K, R_SLSUBBSN, R_SURLAG, R_HRU_SLP, V_SHALLIST.gw and R_OV_N. Among these sensitive model parameters, curve number (R_CN2), saturated hydraulic conductivity (R_SOL_K), Ground water delay (days) (V_GW_DELAY), Manning's "n" values for overland flow (R_OV_N) and available water capacity of the soil layer (R_SOL_AWC) are the top five sensitive parameters with a p-value less than 0.5.

3.4.2 Model calibration and validation

Using the river discharge data obtained from the Minister of Water, Irrigation and Energy (MoWIE), the SWAT model was calibrated at a monthly time scale.

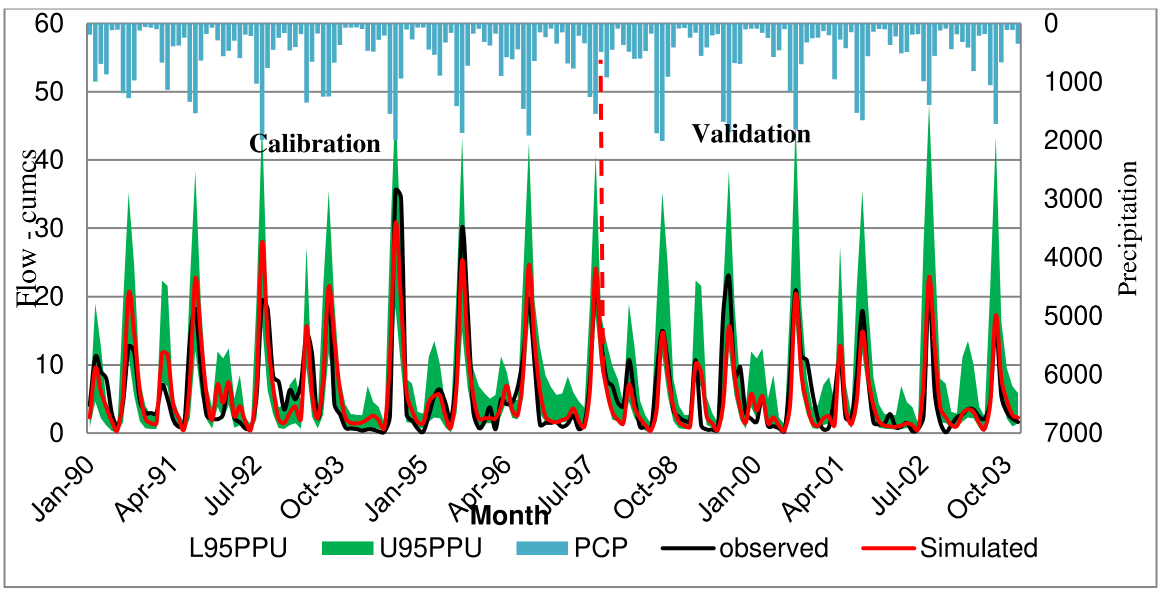


Fig.5 Jewuha river calibration and validation

3.4.3 Model performance evaluation

The performance of the model was evaluated using time series plots of observed and simulated value and statistical measures such as coefficient of determination (R^2), Nash-Sutcliffe efficiency (NSE) and percent of bias (PBIAS). The statistical analysis of the watershed showed very good agreement between observed and simulated monthly flow. For the Jewuha watershed, the model overestimates the flow. The model was most affected by small traditional diversion structures in the Jewuha watershed, which do not have sufficient data to enter the value into the

SWAT model. This makes the model perform less. The p-factor is a good measure of the strength of calibration results. The P-factor is the percentage of measured data bracketed by the 95PPU band and its value is range between 0 and 1. When its value ranges between 0.7 and 1 the percentage of uncertainty is very good. As shown in Table 10, the p-factor was 0.75 for the Jewuha River. This value shows that the 95PPU band is within acceptable ranges in the watershed.

Table 10 Model performance

Objective function	Calibration	Validation
R^2 (Coefficient of determination)	0.74	0.71
NSE (Nash Sutcliff Efficiency)	0.73	0.7
PBIAS (Percent of bias)	-0.8	7.9
RSR	0.51	0.54
p-factor	0.75	0.74

3.4.4 Flow Regionalization

The flow from the gauged watershed to the ungauged watershed was estimated through parameter regionalization using the spatial proximity (SP) technique by Inverse Distance Weighting (IDW). For verification of the regionalization technique in the watershed, the statistical parameters of the objective function are good and this shows that applying the spatial proximity technique to transfer the model parameters to ungauged sub watershed to estimate was acceptable. Thus, the flow in the ungauged sub watershed was estimated using the spatial proximity (SP) regionalization technique.

Table 11 Mean monthly stream flow (m^3/s) of ungauged sub watershed using spatial proximity regionalization

Sub watershed	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Gida	0.5	0.97	0.87	0.83	0.8	0.4	1.06	2.62	1.83	1.13	0.8	0.7
Lomi	4.1	4.62	5.75	6.92	4.1	1.8	8.00	21.5	14.54	8.14	5.22	4.3
Gundifit	1.1	2.13	2.52	3.54	2.7	1.6	5.43	8.29	6.24	3.61	2.4	1.6
Ashmaq	0.1	0.42	0.50	0.74	0.5	0.3	1.24	1.77	1.09	0.46	0.3	0.2
Samet	0.4	0.78	0.90	1.30	0.9	0.6	2.35	2.99	1.77	0.90	0.7	0.5

3.5 Irrigation Water Demand

CROPWAT model results include crop evapotranspiration (ETc) and effective rainfall to estimate the irrigation water requirement of the crop. As shown in table 12, monthly gross irrigation water requirement of maize, cabbage and onion was estimated throughout their full growth periods for both surface, sprinkler and drip irrigation systems.

Table 12 Gross irrigation water demand (mm/month)

Irrigation Methods	Crop type	Jan	Feb	Mar	Apr	May
Surface irrigation	Onion	135.15	59.3	89.85	37	0
	Maize	69.36	50.66	120.57	144	119.94
	Cabbage	123.74	83.41	144.21	74.6	0
	Average	109.42	64.46	118.21	85.2	39.78
Sprinkler irrigation	Onion	90.1	39.53	59.9	24.7	0
	Maize	46.24	33.77	80.38	96	79.96
	Cabbage	82.5	55.6	96.1	49.7	0
	Average	72.95	42.97	78.79	56.8	26.65
Drip irrigation	Onion	79.5	34.88	52.85	21.8	0
	Maize	40.8	29.8	70.92	84.71	70.55
	Cabbage	72.8	49.1	84.8	43.9	0
	Average	64.37	37.93	69.52	50.14	23.52

3.6 Irrigation Suitability Potential

To find the irrigation suitability potential of the study area; land suitability maps, land use land cover suitability maps, distance from stream suitability maps and distance from road suitability maps were overlay in a GIS environment using a weighted overlay analysis tool in the spatial analysis tool. To overlay these maps, the factors are given a weight.

Table 13 Weight developed for factors

Factors	Wj (Weight (%)
Land suitability	47
Land use land cover suitability	27
Distance from source suitability	16
Distance from road suitability	10
Sum	100

The consistency ratio (CR) was 0.02, which is acceptable for weighting the factors to evaluate the irrigation suitability of the watershed.

3.6.1 Surface irrigation suitability

Assessment of the study area for surface irrigaion suitability revealed that 1% (581ha) are highly suitable, 16% (10778ha) suitable, 59% (40013ha) moderately suitable and 24% (16274ha) are not suitable to develop a surface irrigation system. Of the total land area of the study, 51372ha of land are suitable for surface irrigation. The analysis indicates that in the irrigation suitability map,a high portion of the cultivated area is found in the middle low land area and is deemed suitable for surface irrigation due to its high soil depth and flat slope of less than 8%, which is suitable for surface irrigation.

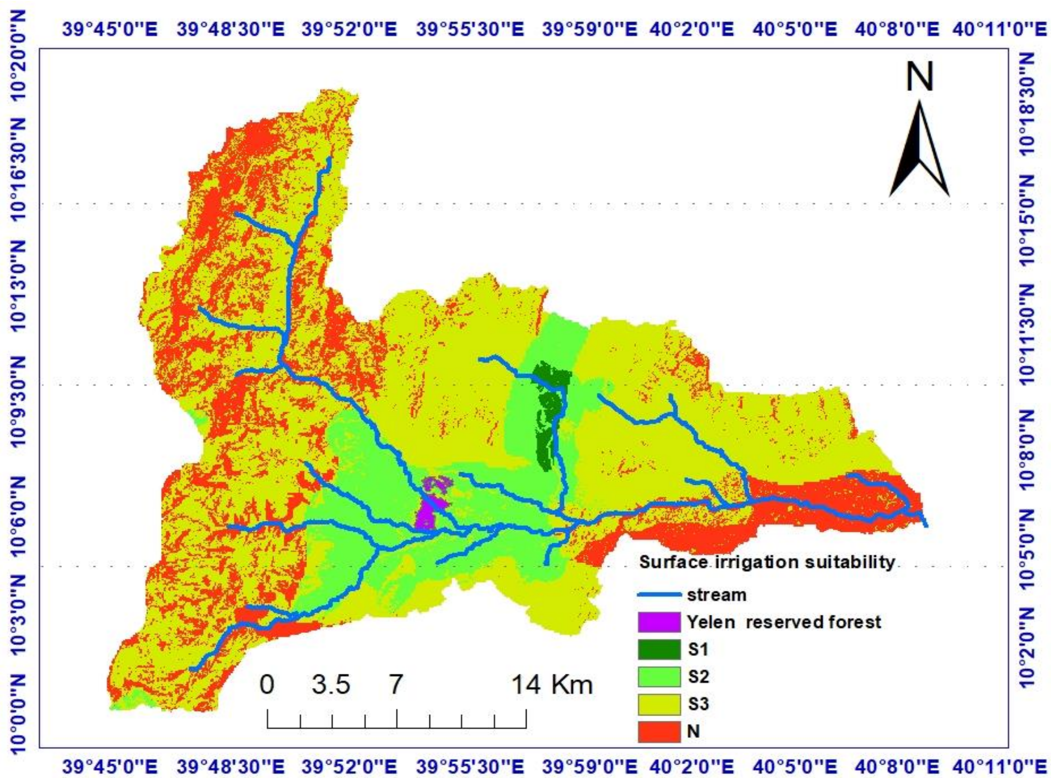


Fig.6 Surface irrigation suitability

3.6.2 Sprinkler irrigation suitability

Assesment of the study area for sprinkler irrigtion suitability revealed that 4.5% (3029ha) are highly suitable, 26.5% (18042ha) are suitble, 46% (31697ha) are moderately suitable and 23% (15088ha) are not suitable to develop a sprinkiler irrigation system. From the total land area of the study, 52768ha of land can be developed by the sprinkiler irrigation system.

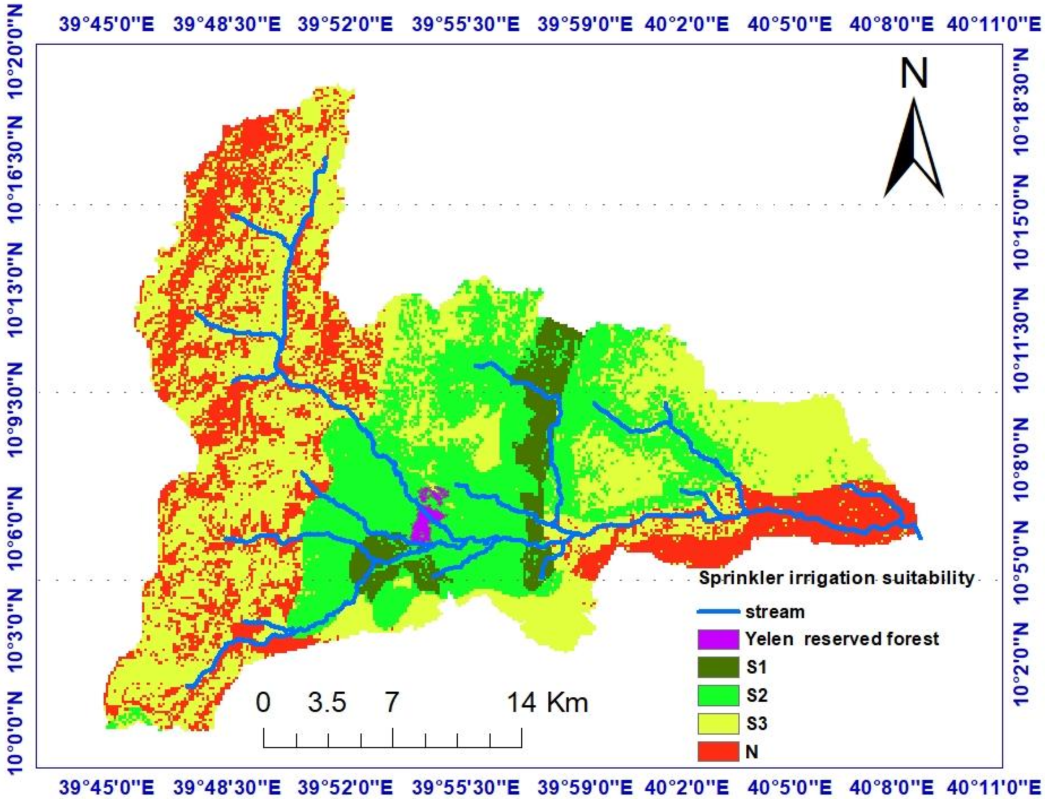


Fig.7 Sprinkler irrigation suitability

3.6.3 Drip irrigation Suitability

The assessment of drip irrigation suitability in the study area revealed that 13% (8498ha) are highly suitable, 25% (16971ha) are suitable, 40% (27282ha) are moderately suitable, and 22% (14855ha) are not suitable for drip irrigation system. From the total land area of the study, 52751ha of land can be developed by the drip irrigation system.

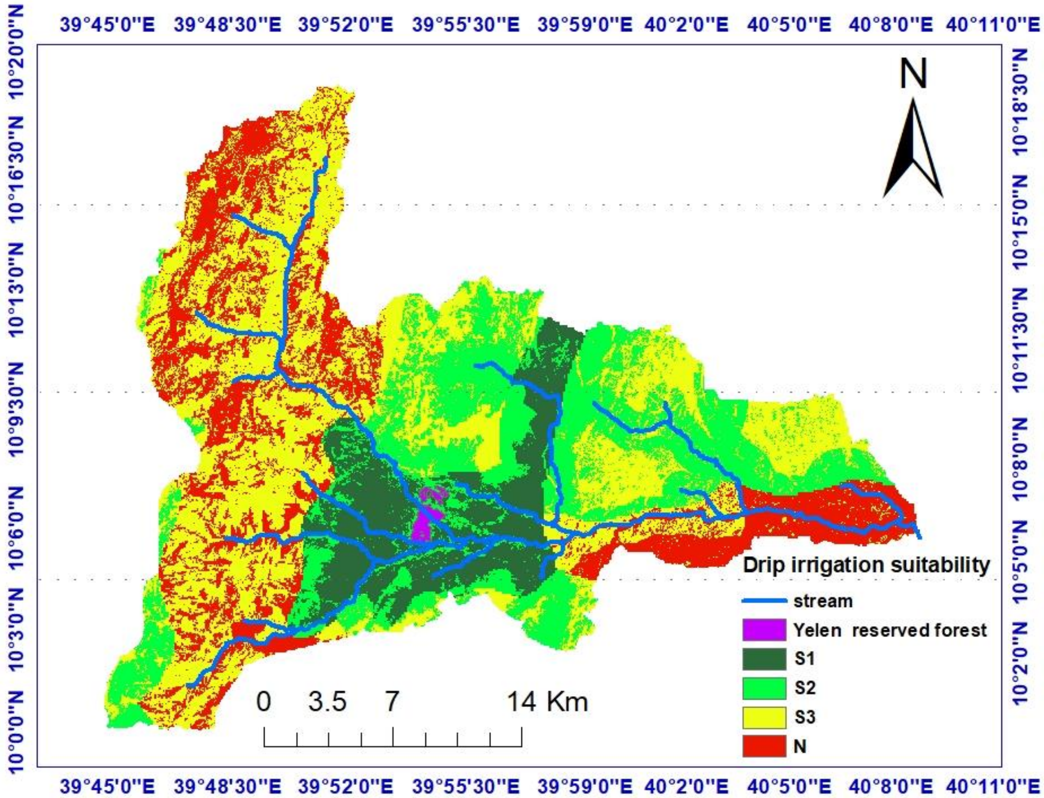


Fig.8 Drip irrigation suitability

3.6.4 Irrigation suitability of river catchments (sub watershed)

The irrigation suitability of river catchments or sub watersheds as shown in table 14 below shows that 315ha of the area in Gida sub watersheds was categorized as highly suitable for surface irrigation, but the remaining sub watersheds are not considered as highly suitable. For sprinkler irrigation suitability system 587ha, 603ha and 2ha of the area in Gida, Gundifit and Ashemaq are categorized under highly suitable for irrigation, respectively.

Table 14 Irrigation suitability of sub watershed

Sub watershed Name	Surface irrigation (ha)				Sprinkler irrigation (ha)				Drip irrigation (ha)			
	S1	S2	S3	N	S1	S2	S3	N	S1	S2	S3	N
Gida	315	678	4409	266	587	3107	1950	25	588	3083	1961	34
Lomi	-	302	10397	7036	-	785	10134	6836	163	729	9928	6909
Gundifit	-	2283	2226	641	603	2213	1721	616	2071	823	1615	641
Ashemaq	-	394	2253	1161	2	467	2203	1138	298	333	2165	1013
Samet	-	163	3769	2225	-	230	3919	2025	32	1255	3018	1848

For drip irrigation suitability systems, all the sub watershed are categorized as highly suitable, from the smallest area, 32ha in the Samet river sub watershed to the largest 2014ha in Lomi river sub watershed. This shows that pressurized irrigation systems are more suitable than surface irrigation systems in the Jewuha watershed. This was due to the fact that, pressurized irrigation method is more suitable for steep slopes than the surface irrigation systems.

3.7 Irrigation Potential Mapping

From the analysis to estimate the irrigation potential from the available surface water and gross irrigation mater demand, the irrigation potential of the watershed was estimated as shown in the table 15 and figure 9.

Table 15 Irrigation potential and surface water available at selected diversion site and their location

Diversion site	Water potential (Mm^3)	GIWR (m^3/ha)			Irrigation potential (ha)		
		Surface	Sprinkler	Drip	Surface	Sprinkler	Drip
Gida	1.06	4173	2780	2460	254	381	431
Lomi	8.4	4173	2780	2460	2014	3021	3415
Gundifit	2.34	4173	2780	2460	560	842	951
Ashmaq	0.34	4173	2780	2460	83	122	138
Samet	0.78	4173	2780	2460	187	281	317

Therefore, as shown in table 15 the actual irrigation potential of Jewuha watershed was found 3098ha for surface irrigation, 4647ha for sprinkler irrigation and 5252ha for drip irrigation systems.

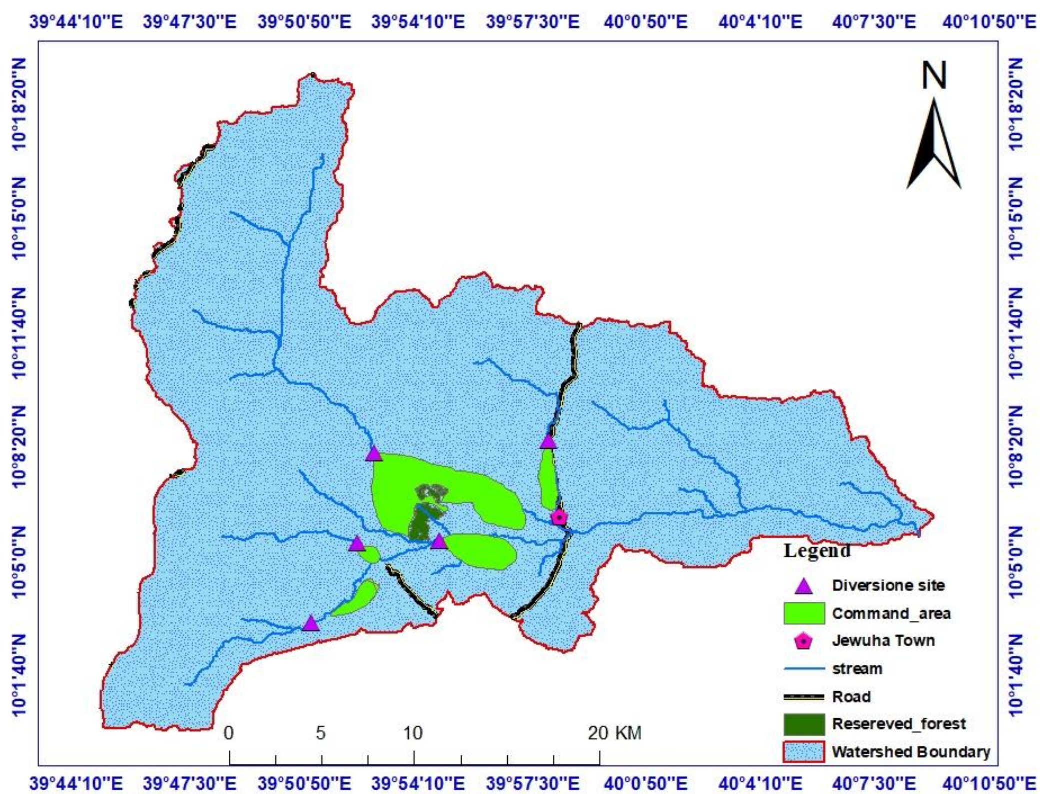


Fig.9 Irrigation potential maps and diversion site location

Conclusion

In this study, the land suitability was analyzed using the parametric evaluation technique by considering topography and soil physical and chemical characteristics. The result showed that 12,373ha of land are suitable for surface irrigation, 31,138ha of land are suitable for sprinkler irrigation systems and 35,433ha of land are suitable for drip irrigation systems. Suitability assessment of LULC, distance from source and distance from road shows that 67, 847ha, 59,183ha and 57,133ha are suitable for irrigation, respectively. From the weighted overlay of suitable land, land use land cover, distance from water resource and distance from road reveals that 1% (581ha) are highly suitable, 16% (10,778ha) are moderately suitable, 59% (40,013ha) are slightly suitable and 24% (16,274ha) are not suitable to surface irrigation system. And 4.5% (3,029ha) are highly suitable, 26.5% (18,042ha) moderately suitble, 46% (31,697ha) slightly suitable and 23% (15,088ha) are not suitable for sprinkiler irrigation system. For drip irrigation system 13% (84,98ha) are highly suitable, 25% (16,971ha) moderately suitble, 40% (27,282ha) slightly suitable and 22% (14,855ha) are not suitable.

To estimate surface water potential, the SWAT model was employed. The model was calibrated and validated by the observed flow. During the calibration and validation, the model performed good to simulate the hydrology of the watershed with a coefficient of determination (R^2), Nash-Sutcliffe efficiency (NSE) and Percent of bias (PBIAS) 0.74, 0.73 and 0.8 for calibration and 0.71, 0.7 and 7.9 for validation in Jewuha watershed. Spatial proximity regionalization technique was used to estimate the water potential for each ungauged sub watershed. The surface water potential of Gida, Jewuha, Gundifit, Ashmaq and Samet sub watershed was 1.06Mm^3, 8.4Mm^3, 2.34Mm^3, 0.34Mm^3 and 0.78Mm^3 respectively.

The gross irrigation water demand was estimated using three major crops grown in the area, viz.maize, cabbage and onion. The average monthly demands were found to be 417mm, 278mm and 245mm for surface, sprinkler and drip irrigation systems, respectively. Possible diversion site were selected based on the available command area to be irrigated below the proposed diversion site, accessible to road, 80% available flow and narrow river width. As a result, five (5) diversion sites were selected. The irrigation potential of the study area was estimated and mapped based on the available water and gross irrigation water demand to the selected diversion site. This result reveals that 3098ha, 4647ha and 5252ha of land are potential for surface, sprinkler and drip irrigation systems, respectively.

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