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GIS Based Surface Irrigation Potential Assessment: A Case Study at Ardy Watershed, Upper Blue Nile Basin, Ethiopia

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Abstract: *Assessment of potential irrigable land and available water resources is essential for the development of irrigated agriculture for addressing food security problems. This study aimed at assessing the water resource availability and irrigable potential land for surface irrigation in Ardy Watershed Blue Nile Basin, Ethiopia. This was done by using Geographical Information System (GIS)-Multi Criteria Evaluation (MCE) methods; a Hydrological Soil and Water Assessment Tools (SWAT) - model and a FAO CROPWAT 8.0 model, Crop water and irrigation requirements program. Soil and Water Assessment Tool (SWAT)-model was used to estimate the water availability and crop water and irrigation requirement. (CROPWAT)-model was used to estimate reference evapotranspiration, effective rainfall, and Net irrigation requirement and to calculate gross irrigation requirement with respect to suitable irrigable land. The gross irrigation requirement was calculated for four selected crops (wheat, barley, potato and maize) and compared with the available flow to get potential suitable land for surface irrigation. The result of the overall weighted overlay analysis of these factors gave about 7886.16ha (38%) of the watershed land considered as highly to moderately suitable whereas* 6345.41ha (30.73%) *were not suitable for surface irrigation in the Ardy watershed. The SWAT model was calibrated and validated. The results of model performance indicators were in the acceptable range (R^2>0.6, NSE>0.5 and PBIAS>±15), showing a good agreement between observed and simulated values for calibration and validation (R^2=0.8, NSE=0.75 and PBAIS=0.3) and (R^2=0.77, NSE=0.71andPBAIS=7.3) respectively. The annual average simulated stream flow was estimated as 6.5m^3/s and the water demand required by the whole major crops was 20.13m^3/s. Finally, the total suitable irrigation potential of the study watershed was 7886.16 ha, which can be irrigated with the available flow of 6.5m3/s. But due lack of available flow only 6252.52ha can be irrigated with the available flow of 6.5 m3/s. The result showed that the water demand of the crops were greater than available flow of the watershed. Therefore the limiting factor is water. To increase irrigation potential of the watershed sprinkler or drip irrigation methods can be used.*

Keywords: *Irrigation potential, Ardy watershed, SWAT model, GIS, Suitability factors, MCE.*

BACKGROUND

With the low productivity of rain-fed agriculture and the need to double food production over the next two decades, water has been considered as the most important factor for the transformation of rain-fed agriculture into most effective and efficient irrigated agriculture (FAO, 1996). To overcome the effects of rainfall variability and unreliability, it is obvious that the utilization of water resources in irrigated agriculture provide supplementary and full season irrigation. Hence, irrigation development is the solution for food insecurity by reducing variation in harvest and intensification of cropping by producing more than one crop per year (Temesgen & Yonas, 2016).

Ethiopia is a country whose economy primarily depends on Agriculture. Agriculture plays essential role in the economy of the country. It directly supports 85% of the population’s livelihoods, 43% of the Gross domestic product (GDP) and contributing over 80% of foreign exchange earnings of the country (IWMI, 2010). The country depends on the rain fed agriculture with limited use of irrigation for agricultural production. It is estimated that more than 90% of the food supply in the country comes from low productivity rain-fed smallholder agriculture and hence rainfall is the single most important determinant of food supply (FDRE, 2011). Rainfall in much is on the other hand often erratic, unreliable, and variable. And associated droughts historically have been major causes of food shortages and famines in the country (Woldeamlak, 2009)

According to earlier studies, the potential irrigable land of the country was estimated to be 3.7million ha (Awulachew *et al.*, 2007). Some of the recent studies refined this potential irrigable land as 5.3 Million hectares (Awulachew *et al.*, 2010) and 11.1Million hectares (MoA & MoWIE, 2018). Irrigation development is playing great role in adapting to climate change, achieving food security, and improving house hold incomes. But due to technical, financial, management and other problems the country has not utilized its potential very well (Gebremedhin, 2015). Surface irrigation is the one from irrigation methods, which is the application of water by gravity flow to the surface of the field. It is the oldest and still the most widely used method of water application to agricultural lands (FAO, 2002). The MCE technique identifies the potential suitable land by considering multiple factors affecting the suitability of a certain land area for irrigation (Abeyou *et al.*, 2015).

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This study was assessed overall irrigation potential for surface irrigation in Ardy watershed which is tributaries of Upper Blue Nile Basin. The study was assessed suitable land in terms of suitability parameters, the amount of stream flow and the gross irrigation requirement of dominant crops that cultivating in the study area. Therefore, assessed and identified suitable irrigation potential of watershed in the area plays a vital role in enhancing people life standards and irrigation sector of the country.

MATERIAL AND METHODS

Description of the study area

The figure 1 shows that the study area was conducted in the Ardy Watershed, Upper Blue Nile Basin, bordered on the north by Benishangul Gumuz, Mandura Woreda, on the east by Engibara, on the south by Zigem. Geographically it is located between latitudes of 10°52'0"N-11°1'0"N and longitudes of 36°31'0"E-36°48'30"E, which covers a watershed area of 217 km^2.

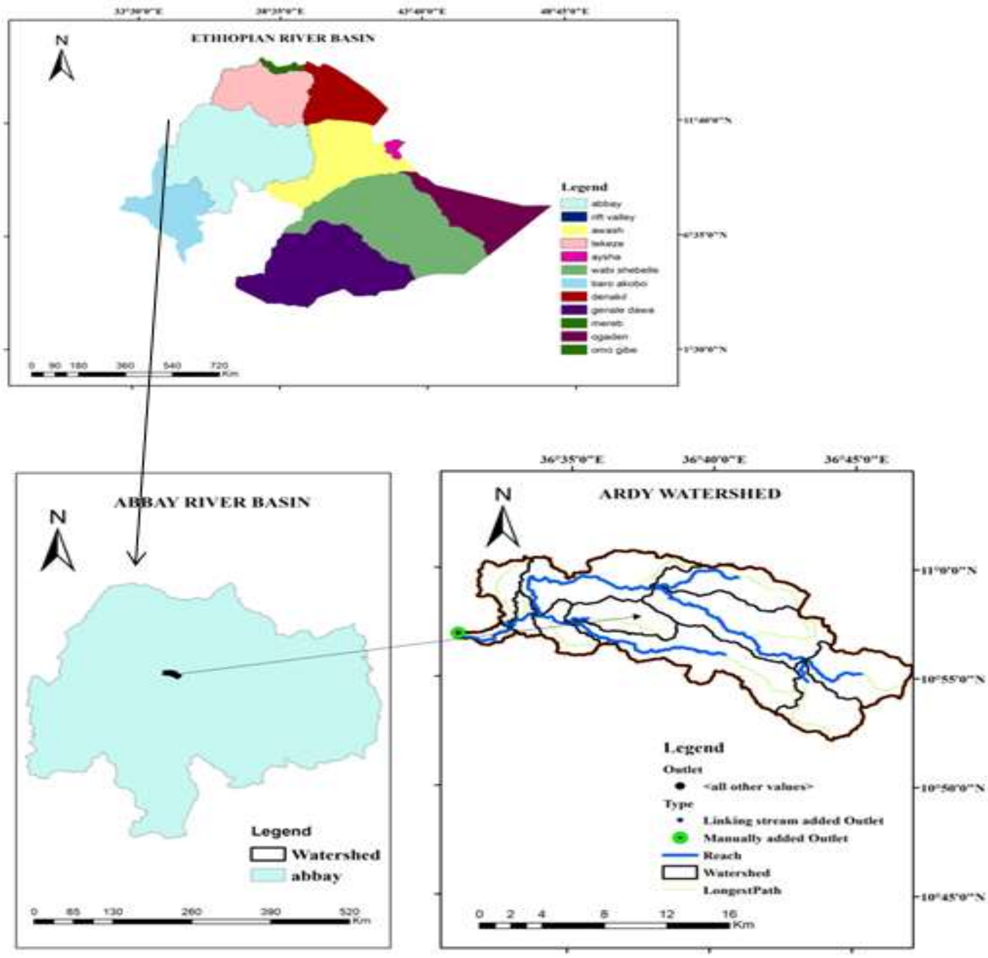

Figure 1. Map of the study area

Topography

The figure 2 shows that the Ardy Watershed was characterized by diverse topographic conditions. Land classification factor were evaluated by topographical qualities of slope gradient. The elevation of the study area is extending from 1,635 to 2,835 meters above mean see level.

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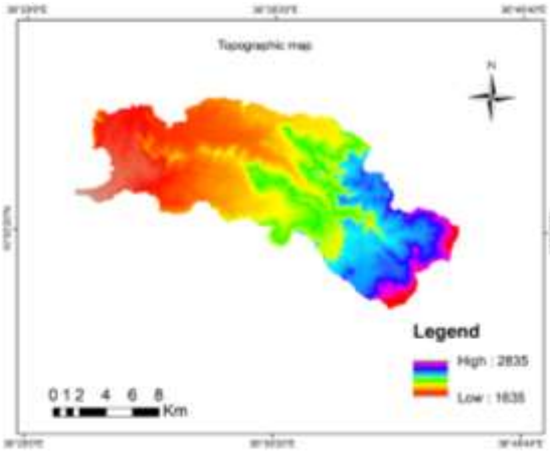

Figure 2. Topographic map of study area

Climate

The climate of the study area is classified as semi-humid, which is characterized by contrasting seasons (i.e., very wet and very dry seasons). The study area has a bimodal distribution rainfall receiving the highest amount of rainfall season between May and October while the short rainy season is between February and April (Menal *et al.*, 2011). The meteorological/climatic elements include rainfall, maximum and minimum temperature, wind speed, solar radiation, and relative humidity and sunshine hours. The figure 2. 3 indicate that the Ardy watershed has an annual rainfall ranging between 1333mm to 2855mm. The mean monthly maximum and minimum temperature in the watershed was between 23.3℃ to 31.6℃ and 11.2℃ to15.2℃.

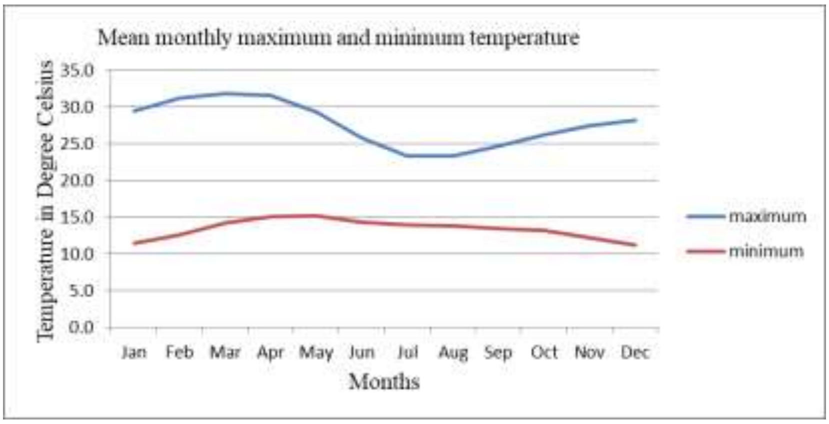

Figure 2. Mean monthly maximum and minimum temperature from 1996-2018

Soil

The major soils of the Ardy watershed were extracted from Harmonized world soil data base. The Figure 4 indicates that the major soil types in the watershed. These are Humic Nito Soil and Eutric fluvi soil with clay (light) texture and loam texture soils respectively. The dominant soil in the watershed is Eutric Fluvi soil which covers 65% of total study area.

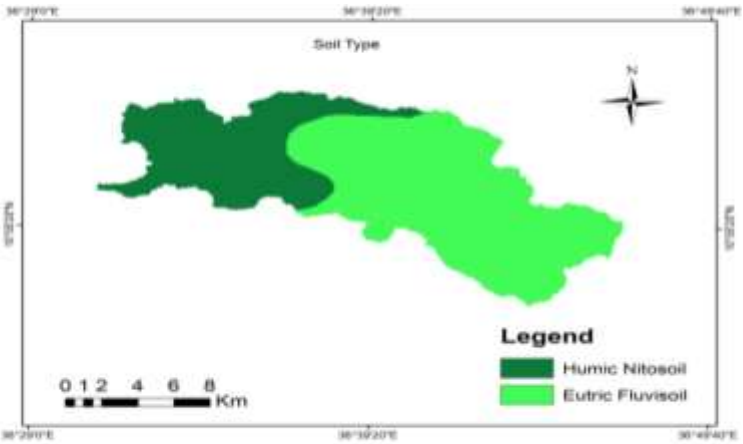

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Figure 3. Major soil type of the study area

Land use and land cover

The figure 5 shows that the study area was characterized by Agriculture, grassland, forest, shrub land, water body and built up (settlement). The area proportion of the land use and land cover was listed below in table 1.

Table 1: Land use land cover of study area

Land use and Land cover class	Area coverage (ha)	Proportion (%)
Shrub and bush land	5464.80	25.16
Water body	61.29	0.28
Built up(settlement)	50.76	0.23
Agriculture	7065.63	32.53
Grassland	2779.92	12.80
Forest	6298.00	29.00

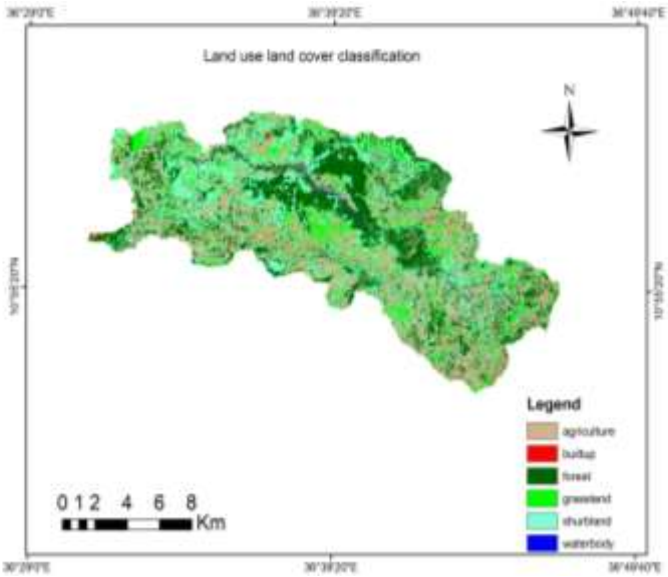

Figure 4. Land use and land cover map of the study area

DATA COLLECTION AND ANALYSIS

Assessment of Suitable Land for Surface Irrigation

Data type and Data collection methods

Suitable land for surface irrigation is carried out by considering slope, soil depth, soil texture, soil drainage, land cover/use data and distance from water source. The data type and data source are listed below.

Table 2: Data type and data collection method

Data type	source	purpose
Soil	From FAO/IIASA/ISRIC/ISSCAS/JRC. “Harmonized World Soil Database’’ (Version 1.2).	for soil suitability analysis
land use land cover 2018(30m*30m), path /row(170/052)	Satellite image from http://earth explorer.usgs.gov/	for land use and land cover suitability
Digital Elevation Model	http:// earth explorer.usgs.gov/	for slope suitability
Distance from water source	from DEM using stream network as input	For River proximity suitability

Data Analysis

The land suitability assessment of surface irrigation was estimated by using Multi-Criterion Evaluation (MCE) method with Geographic information system (GIS). Land suitability was determined by assigning weights (ranks) and constructing pairwise comparison matrix to each factor that likely undertaking the surface irrigation methods. Finally the suitability parameters were weighted together on the overlay analysis tool to get suitable irrigable land. The factors

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that considered are soil, slope, land use and distance from water source (Abeyou *et al.,* 2015).

Factors used to asses land suitability for surface irrigation

According to FAO (2007), the land suitability analysis is an evaluation/decision problem involving several factors. The assessment of terrain condition and soil characteristics is essential part of the land evaluation and forecasting exercise applied to agriculture. Their assessment provides the information about the limitations of the land for surface irrigation development. According to Satpathy *et al.* (2017), the limitation of the land is derived from the quality of the land. Hence the assessment of the land for surface irrigation was carried out by considering the factors included physical land features (land use land cover, slope, soil), and distance from water source (Rediet *et al.,* 2020). For the analysis of suitable land for potential surface irrigation development the factors reclassified in to different suitability class.

Table 3: Land suitability classification classes

Class	Suitability	Description
S1	Highly suitable	Land without significant limitations
S2	Moderately suitable	Moderately severe limitations which reduce productivity or benefits or increase required inputs
S3	Marginally suitable	Overall severe limitations ;given land use is only marginally justifiable
N	Not suitable	Limitations not currently overcome with existing knowledge Within acceptable cost limits

Source: (FAO, 1996) an interactive multi criteria analysis for land resource appraisal

Slope Suitability Assessment

Slope is the most important topographical factors influencing land suitability for surface irrigation (Abebe, 2019). The slope map was derived from DEM with the application of spatial analysis tools (surface analysis) in Arc tool box with in Arc GIS. The slope derived from the DEM was classified into four suitability classes S1 (0-2%), S2 (2-5%), S3 (5-8%) and N (>8) based on the classification system (FAO, 1997).

Table 4: slope Suitability assessment

Legend	Percent (%)	Factor of rating
1	0-2	S1
2	2-5	S2
3	5-8	S3
4	>8	N

Source: (FAO, 1996) an interactive multi-criteria analysis for land resources appraisal.

Soil Suitability Assessment

Soil is important factor for determining land suitability assessment for surface irrigation development. The physical properties of the soil feature layers of each physical soil parameter; soil texture, soil drainage, and soil depth prepared firstly. Then the feature layers were converted into raster layer using conversion tool "To Raster. Finally, soil suitability map of each soil physical parameter was developed with the factor rating of S1,S2,S3, and N through reclassified raster layers based on the (FAO,1997) soil classification guideline for surface irrigation .

Soil depth

Soil depth refers to the thickness of the soil materials which provide structural provision, nutrients and water for plants (Edmealem, 2018). The depth of the soil exploited by plant roots was important criterion for land evaluation. The soil depth variation from place to place determines the growth of the plant and also affects the growth of plant roots (Megrsa, 2020).

Table 5: Soil depth suitability for surface irrigation

No	Soil depth factor(cm)	Factor rating
1	>100	S1
2	100-80	S2
3	80-50	S3
4	<50	S4

Source: FAO, (1997) Irrigation potential In Africa, Basin approach.

Soil Texture

Soil texture is the relative proportion of sand, silt and clay of the dominant soil for each soil map polygon. Based on its particles size, soils are divided into three major types of soil textures .These are coarse, medium, and fine textures. The soil texture extracted from Harmonized world soil data base shows that the study area was characterized as clay (light) and loamy soil.

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Table 6: Soil texture suitability for surface irrigation

No	Texture	Suitability class
1	Clay	S1
2	loam	S2
3	Fine Sandy loam	S3
4	Loamy sand	S4

Source: (Mandal *et al.,* 2017; & Kebede, 2010)

Soil drainage

Soil drainage refers to the flow of water through the soil, and the frequency and duration of periods when the soil is free of saturation under natural condition. The soil drainage is important as it controls the continuous movement of water and salt through the soil profile (Megrsa, 2020).

Table 7: Soil drainage suitability for surface irrigation

No	Drainage	Suitability class
1	Well drain	S1
2	Moderately drain	S2
3	Poorly drain	S3
4	Imperfectly drain	S4

Source: (FAO, 1997) Irrigation Potential in Africa, Basin Approach.

Distance from water source

To identify suitable land for surface irrigation close to the water source GIS (spatial analyst tool →Distance → Euclidean distance) by considering river network as input factor. Then using displayed output result the reclassification was done (spatial analyst tool > reclass > reclassify). The suitability class of land parcel with respect to river proximity is determined by its distance in relation to the rivers. After categorizing the distance map of the river in to four classes of equal ranges, the closer distance was classified as highly suitable(S1) and the farthest distance as not suitable(S4) (Abeyou,2015).

Table 8: Distance from water source suitability for surface irrigation

No	Distance to water source (Equal interval/ranges)	Suitability classes
1	Closer distance	S1
2	Moderately closer distance	S2
3	Marginally closer distance	S3
4	Furthest distance	S4

Source: (Abeyou *et al.,* 2015) Assessment of surface water irrigation potential in the Ethiopian Highlands: The Lake Tana basin.

Land use Land Covers Assessment

Land use land cover is also the factor, which was used to evaluate the land suitability for surface irrigation. Land use land cover of the study area was obtained from the satellite imagery. Its classification was done by using supervised classification methods. The major land use land cover of the catchment was classified as: agriculture, grassland, water body, forest, built up, and shrub and bush land.

Table 9: Land use and land convers suitability criteria

Class	Suitability	Description
S1	Highly suitable	Cultivated-dominantly, moderately grassland, open- bushed, state farm
S2	Moderately suitable	Woodland-open, riparian, bush land-dense
S3	Marginally suitable	Forest-open, cultivated-irrigation, shrub
S4	Not suitable	Woodland, forest-dense, bamboo, urban, water

Source: (FAO, 1996) an interactive multi criteria analysis for land resources appraisal

Image classification

Image classification serves a specific goal: converting image data in to thematic map (yared, 2014).

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Image classification of the study area was done based on the different spectral characteristics of different materials on the Earth's surface. According to Richareds, (1984), there are two approaches to classify spectral images, unsupervised and supervised. Unsupervised classification is the method in which image pixels are assigned to spectral classes without the user having detail information about the study area. Whereas, supervised classification is a method that requires the analyst to identify known areas therefore the user have more information or pervious knowledge about the study area. The six (agriculture, water body, grassland, built up, forest, shrub and bush land) land use land cover classification was made by using supervised classification with maximum likelihood ERDASE imagine 2014.

Estimating Surface Water Availability

Data type and Data collection methods

Surface water Availability of the watershed was assessed by using the simulated value of flow from SWAT model output. The stream flow discharges that was obtained from the Ministry of Water, Irrigation and Electricity; department of hydrology was used for flow calibration and validation using SWAT CUP. The input used to swat model are stream flow data, soil data, LuLc data to assess surface water availability.

Table 10: Data type and data collection

Data Type	Source	Purpose
stream flow	from Ministry of water, irrigation and Energy	for calibration and validation
land use land cover 2018(30m*30m),path/row(150/052)	satellite image from http://earth explorer.usgs.gov/	for land use and land cover suitability
Digital Elevation model	http:// earth explorer.usgs.gov/	for slope suitability
soil	From FAO/IIASA/ISRIC/ISSCAS/JRC. "Harmonized World Soil Database (Version 1.2).	for soil suitability analysis
meteorological data	from National meteorological services Agency of Ethiopia	for estimating GIWR and flow out put

Data Analysis

Prior to irrigation development, the irrigation potential of the watershed has to be assessed because assessing the suitability of land and water is critical to the development of productive and economically variable irrigation schemes (FAO, 1997). Therefore, water supply (water quantity and seasonality) is the important factor to evaluate the land suitability for irrigation according to the volume of water during the period of year which it is available (Megersa *et al.*, 2020). Agriculture activity and water potential are closely related to the temporal and spatial patterns of climatic variables such as rainfall, temperature, relative humidity wind speed and sunshine hours and success of surface water potential strongly depends on climatic situation of an area. The availability of surface water potential resources for potential irrigation was assessed for the whole crop growth season. Gross irrigation demand for the selected major crops and the available mean monthly flow of the river were calculated and compared. The measured stream flow data of Ardy River were used to calibrate and validate with the simulated SWAT flow output. There are four surrounding stations in the watershed Chagni, Injibara, Kidamaja and Mandura climatic stations. From those stations Chagni station is the principal station selected for the study.

Filling of Missing Meteorological Data

Most of meteorological stations in the country have incomplete data records and it is necessary to estimate the missing records to keep the continuous time series of the data. The record at many rain gauge stations may consist of short breaks due to several reasons such as absence of the observer, instrumental failure and it is the main factors responsible for gaps and inconsistencies in the available series data. If data gaps are big, incomplete time series may hide the pattern of the data and they may considerably distort the result of any statistical analysis. It is better to estimate these missing records and fill the gap rather than to leave them .there are many available methods of estimating missing values .for this study, the missing values of daily rainfall and temperature recorded were completed by using normal ratio method provided in due to the rainfall measured at different nearby station of the watershed. According to Dingman, (2002) normal average annual precipitation of adjacent stations differs by more than 10% of the normal average rainfall from the missed data stations.

Thus, in this study missing records of the rainfall stations were estimated by using normal ratio method (NRM) using equation 2.1.

$$Px = \frac{Nx}{M} * \left[\frac{P1}{N1} + \frac{P2}{N2} + \cdots \frac{Pm}{Nm}\right] \ldots\ldots\ldots\ldots\ldots\ldots 2.1$$

Consistency Rainfall Data

A double mass curve (DMC) was used to check the consistency of rainfall for adjustment of inconsistent data. Before rainfall records are used in such studies, they should be tested and errors have to be removed to ensure that any detected are due to meteorological causes and not to changes in gauge location, in exposure, or observational methods. The consistency of rainfall data was checked using double mass curve through plotting the graph of cumulative average annual rainfall of each station collected against the cumulative average annual rainfall records of all station collected as the selected stations in the periods. The double mass curve was applied for consistency. To check the degree of consistency the values of the coefficient of correlations were used and summarized in table 11.

Table 11: Coefficient of correlation for double mass curve analysis (Nemec, 1973)

Sl. No	Correlation(R)	Rate of Correlation
1	r =1	Direct linear correlation
2	0.6≤ r < 1	Good direct correlation
3	-0.6< r < 0	Insufficient–reciprocal correlation
4	-1< r < 0.6	Good reciprocal correlation
5	r = -1	Reciprocal linear correlation

As shown in figure 8 the proportionality and accuracy of stations, shows good correlation between the station recorded and their corresponding base stations, thus the station less affected by inconsistency and can be used for further analysis in the watershed.

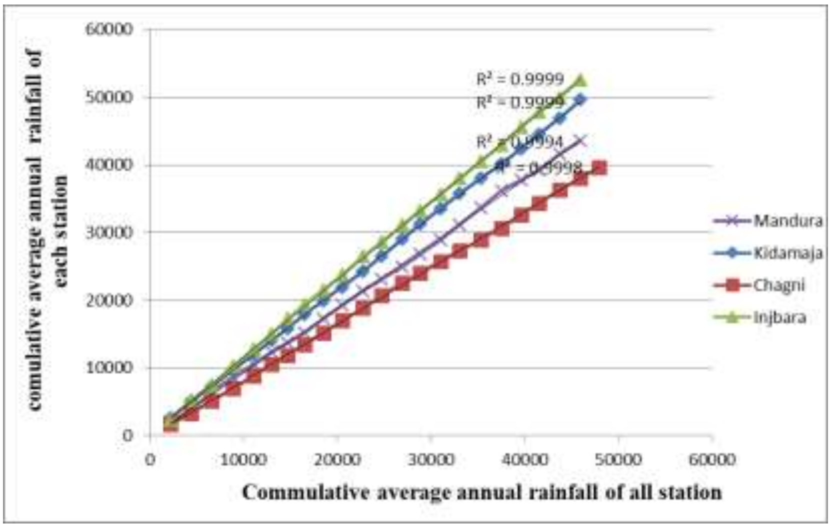

Figure 5: Double Mass Curve of the Station

SWAT Model Setup

The available surface water of the watershed was estimated by using the meteorological and spatial data of the study by using SWAT model. The SWAT model is a semi-physically based model for evaluating land management practices, discharge, sediment transport, nutrient cycling (Getnet *et al.*, 2019). The Arc-SWAT 2012 is an Arc View extension. It provides a graphical user interface that allows GIS data to be easily formatted for use in SWAT model simulations. Arc SWAT breaks pre-processing into four main steps: watershed delineation, HRU analysis (LULC, topographical, soil characteristics) weather data definition (daily precipitation, maximum and minimum temperature, solar radiation, wind speed and relative humidity) and SWAT simulation.

The simulations of hydrology of a watershed are done in two separate divisions. One is land phase of the hydrological cycle that controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in the each sub basin. Hydrological components simulated in land phase of the hydrological cycle are canopy storage, infiltration, redistribution, evapotranspiration, lateral subsurface flow, surface runoff, ponds, tributary channels and return flow. The second division is routing phase of the hydrological cycle that can be defined as the movement of, sediments, nutrients and organic chemicals through the channel network of the watershed to the outlet. In the land phase of the hydrological cycle, SWAT simulates the hydrological cycle based on the water balance equation.

$$SWt = SWo + \sum_{i=1}^{t}(Rday - Qsurf - Ea - Wseep - Qgw) \quad \ldots\ldots 2.2$$

Where SWt=the final soil water content (mm),
SWo=the initial soil water content on day i(mm)
t=the time (days),Rday=the amount of precipitation on day i(mm)
Qsurf=the amount of surface runoff on day i(mm),
Ea= the amount of evapotranspiraation on day i(mm)
Wseep=the amount of water entering the vadose zone from the soil profile on day i (mm)
Qgw=the amount of return flow on a day i (mm)

In this study SWAT model has been used because of:-

- The model simulates the hydrological process in the watersheds
- It is readily and freely available.

- It is computationally efficient.
- And also it capable of yearly, monthly and daily simulation over long periods.

SWAT Model Input Data

Digital Elevation Model (DEM)

DEM with the resolution of 30x30m was used for SWAT model to delineate the watershed and to analyze the drainage pattern of the land surface terrain and sub basin parameters, such as slope gradient, slope length of the terrain and the stream network characteristics, such as canal slope, length and width. The DEM was obtained by downloading from Shuttle Radar Topographic Mission (SRTM) site of United States Geological Survey (USGS).

Land Use Land Cover Data

Land use is one of the most important factors that affect surface irrigation, evapo-transpiration and surface erosion in watershed. A given land use may take place on one, or more than one pieces of land and several land uses may occur on the same piece of land. Land use land cover in this way provides a basis for identifying the possible land suitability for irrigation with precise and quantitative economic evaluation. Therefore, matching of existing land use land cover with topographic and soil characteristics to evaluate land suitability for irrigation with land suitability classes, present possible lands for new agricultural production (Boonyanuphap *et al.*, 2004). The reclassification of the land use map has done to represent the land use according to the specific land cover types.

Table 12: Land use land cover classification for SWAT database

Land use land cover	Land use according to SWAT database	SWAT ocde
Shrub and bush land	Range –brush	RNGB
Water body	Water	WATR
Urban land	Residential –low density	URLD
Agricultural land	Agricultural land –Generic	AGRL
Grassland	Range-Grasses	RNGE
Forest	Forest-mixed	FRST

Soil Data

Soil is the most important factor for land suitability evaluation of irrigation in agriculture. It is the one important input data in SWAT model. Physical soil properties are the most dominant factor that determines the land suitability for irrigation. These physical soil properties include soil depth, soil texture and soil drainage .there are two types of soils in the study area. These soils were entered in to the SWAT data base with their detail properties in the HRU's portion of the SWAT interfere.

Table 13: Soil classification for SWAT database

No	Soil type	SWAT code
1	Humic Nito soil	NTu
2	Eutric Fluvi soil	FLe

Meteorological data

The SWAT model requires climate data which is very important for this study such as precipitation, maximum and minimum temperature, sunshine hours, wind speed and relative humidity. These data were collected from ministry of National meteorological services Agency of Ethiopia (NMSA). All meteorological stations having precipitation data only but only Chagni station were synoptic stations having all types of climatic data (precipitation, maximum and minimum temperature, relative humidity, sun shine hours, and wind speed). All data were prepared in text format for each station so that the SWAT model can understand them. These data are used to estimate calibration and validation of SWAT model.

Table 14: Representative meteorological stations in the watershed.

Stations Name	Latitude (degree)	Longitude (degree)	Elevation (meter)
Chagni	10.974	36.499	1614
mandura	11.5	36.5	1184
Kidamaja	10.9984	36.679	1928
Injibara	10.9954	36.9193	2568

SENSITIVITY ANALYSIS, CALIBRATION AND VALIDATION

Sensitivity analysis

After all the input data required for SWAT model were properly loaded, sensitivity analysis of parameter was done using the SWAT interface for the whole watershed (Van Griensven *et al.*, 2006). Before model calibration parameter of sensitivity analysis was done using the SWAT CUP2 sequential uncertainty fitting -2(SUFI2) algorithm global sensitivity methods,

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or the whole catchment area. Parameters with small sensitivity values do not significantly affect the output; hence they are neglected from calibration process. Parameters with medium and high sensitivity values have significant effect on output of the model and used for calibration process to get better result. The sensitivity of each parameter was identified by using the t test, and p values. P values were used to determine the significance of the sensitivity a value close to zero has more significance and the t test provides a measure of sensitivity ,hence larger absolute values are more sensitive(Abbaspour,2015). Generally, 10 hydrological parameters related to stream flow were considered for sensitivity analysis in the study area**.**

Calibration

Model calibration is a means of modifying model parameters to match with the observed data as much as possible, with limited range of deviation accepted. It is also an effort to parameterize a model to a given set of local conditions, thereby reducing the prediction uncertainty. Model calibration is the modification of parameters values and comparison of predicted output of interest to measured data until a defined objective function is achieved (James *et al.*, 1982).

After the sensitive parameters were selected, then simulates the stream flow using default parameters values for the two third of the total data (1998 to 2001) was used for calibration. The default simulation outputs were compared with the observed stream flow data on study area and sometimes it is necessary to change parameters in the calibration process and the range of parameter value based on their absolute values.

After each calibration ,checking the model performance values of R^2 and NSE values and the procedure continued until the acceptable calibration model performance statics R^2 >0.6,NSE >0.5 and PBAIS>±15 (Santhi *et al.*,2001; & Moriasi *et al.*, 2015) were achieved. Simulation has done until the average simulated value come closer to the measured value. Measured flow data of 4 years from the period January1, 1998 to December 31, 2001 was used for calibration.

Table 15: Performance evaluation values and performance classification

Statistical criteria	**Values**	**Performance classification**
NSE	0.75 to 1	Very Good
	0.65 to0.75	Good
	0.5 to 0.65	satisfactory
	0.4 to 0.5	acceptable
	< 0.4	unsatisfactory
PBAIS	<±1	Very Good
	±10 to ±15	Good
	±15 to ±25	Satisfactory
	≥±25	unsatisfactory
R^2	>0.6	Acceptable

Source: Moriasi *et al.* (2015). Hydrologic and water quality models: performance measures and evaluation criteria.)

Validation

Model validation is testing of calibration model results with independent data set without any further adjustment at different spatial and temporal scales (Neitsch, 2002). Validation is comparison of the model outputs with an independent dataset without further adjustments of the values of the parameters. The process continued (validation process) until simulation of validation period stream flows confirmed that the model performs satisfactorily. Checking the R^2 and NSE values after each simulation and calibrate at least until the minimum recommended values were embraced by the; R^2>0.6, NSE>0.5 (Santhi *et al.*, 2001). Independent measured flow data of 3years from the period January 1, 2001 to December 31, 2004 one-third of data was used for validation.

Model Performance Evaluation

To evaluate the model simulation output relative to the observed data, model performance evaluation is necessary. To evaluate model performance during calibration and validation, statistical measures as well as graphical representations at monthly time set up were used. These were employed to confirm the relationship between predicted values and observed values. The following three performance measures were used during the calibration and validation period: percent bias between simulated and observed data (PBAIS), Coefficient of determination (R^2), and Nash and Sutcliffe simulation efficiency (NSE).

Coefficient of Determination (R^2)

Coefficient of determination (R^2) value is indicator of strength of relationship between the observed and simulated values. This value measures how well the simulated versus observed regression line approaches an ideal match and ranges from 0 to 1,with a value 0 indicating no correlation and a value of 1 representing that the predicted dispersion equals the measured dispersion (Krause *et al.*, 2005).

$$R2 = \frac{[\sum(Qo-mean.QO)(Qs-mean.Qs]2}{\sum(Qo-mean.Qo)2\sum(Qo-mean.Qs)2} \ldots\ldots\ldots 2.3$$

Nash and Sutcliffe Efficiency (NSE)

The Nash-Sutcliffe efficiency (NSE) indicates how well the plot of observed versus simulated value fits the 1:1 line. The value ranges from negative infinity to one .The values greater than 0.5 indicates the model simulated value predicted better. A value greater than 0.5 is acceptable performances (Santhi *et al.,* 2001).

$$NSE = 1 - [\frac{\sum(Qo-Qs)2}{\sum(Qo-mean.Qo)2}] \ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.4$$

Percent bias (PBIAS)

The PBAIS measures the average difference between the simulated and measured values for a given quantity over a specified period expressed as a percentage. The optimum PBAIS values are zero and low indicates that the model simulation is satisfactory. Positive values indicate a tendency of the model to underestimate while negative values indicate overestimation (Moriasi *et al.,* 2015).

$$PBAIS = [\frac{\sum(Qo-Qs)}{\sum Qo})] \ldots\ldots\ldots\ldots 2.5$$

Estimating Irrigation Water Requirement for Selected Dominant Crops

Data Type and Data Collection

The water requirement of a crop depends on the climatic conditions. Under the same condition different crops require different amount of water and the quantities of water used by particular crop vary with its stage of growth. Initially during seeding, developing and early growth a crop uses water at a relative slow rate. The rate will increase with growth of crop reaching the maximum in most crops as it approaches flowering and then decline towards maturity. Irrigation water requirement of crops was estimated by CROPWAT model. The data type and source are listed below;

Meteorological Data

The meteorological data was collected from National Meteorological Agency.

Crop data

The major cultivated crops in the study area were wheat, barley, maize and potato. The prominent details of the crops considered for the study was as per FAO guidelines.

Soil data

Soil characteristics considered for estimation of crop water requirement are important to available water content and depth of soil.

CROPWAT input data

Meteorological data

The Meteorological data includes the 23years climate data which are precipitation, temperature (maximum and minimum), relative humidity, wind speed and sunshine hours of the study area were collected from Ethiopia meteorological agency was used to calculate irrigation water requirements of the crops which are dominant in the study area.

Crop data

The major cultivated crops in the study area were wheat, barley, maize and potato. The prominent details of the crops considered for the study was as per FAO guidelines.

Soil data

Soil characteristics considered for estimation of crop water requirement are important to available water content and depth of soil.

Data Analysis

The irrigation water requirement of the four dominant crops in the study area was analyzed by using CROPWAT 8.0 model. CROPWAT is a computer program developed by land and water development division of FAO which calculates reference evapotranspiration, crop water requirements, irrigation water requirements, and scheme supply, to develop irrigation schedules under various management conditions and to evaluate rain fed production and drought effects (Suredran *et al.,* 2015).

It is used as a practical tool to carry out standard calculations for reference evapotranspiration, crop irrigation requirements, cropping Patten and more specifically the design and management of irrigation schemes. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of production under rain fed conditions or deficit irrigation (FAO, 1992). It use as input meteorological data, crop data, soil data to estimate irrigation water requirement. The equation that used to calculate crop water requirements are listed below:-

ETc =ETo*Kc…………………2.5

Where ETc. is crop evapotranspiration , ETo is the rate of evaporation from an extensive surface of green grass cover of uniform height, actively growing, completely shading the ground and with no shortage of water and Kc is the crop coefficient during the initial, mid and development stage. ETo Expresses the evaporative demand of the atmosphere at a specific location and time of the year and does not consider crop and soil factors.

Penman-Monteith method for calculating ETo

It is the method used for estimating evapotranspiration when the data which are temperature, relative humidity, radiation and wind speed are available.

$$\mathbf{ETo}=\frac{0.408\Delta(Rn-G)+\gamma\frac{900}{T+273}U2(es-ea)}{\Delta+\gamma(1+0.34U2)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.6$$

Where:

ETo = Reference evapotranspiration (mm/day)

Rn = Net radiation at the crop surface (MJ/m2 per day)

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G = Soil heat flux density (MJ/m2 per day)
T = Mean daily air temperature at 2 m height (°C)
U2 = Wind speed at 2 m height (m/sec)
es = Saturation vapour pressure (kPa)
ea = Actual vapour pressure (kPa)
es - ea = Saturation vapour pressure deficit (kPa)
Δ = Slope of saturation vapour pressure curve at temperature T (kPa/°C)
γ = Psychrometric constant (kPa/°C).

NIR = ETc − Pef ………………2.7

NIR= Net irrigation requirement (mm)
Pef = effect rainfall (mm)

$$GIWR = \frac{SWD*Acrop}{E} \quad ……........2.9$$

Where:
E = water conveyance efficiency
GIWR = Gross irrigation requirements (m^3/s)
SWD = Scheme water demand (L/s/ha)

RESULTS AND DISCUSSION

Land Suitability Analysis for Surface irrigation

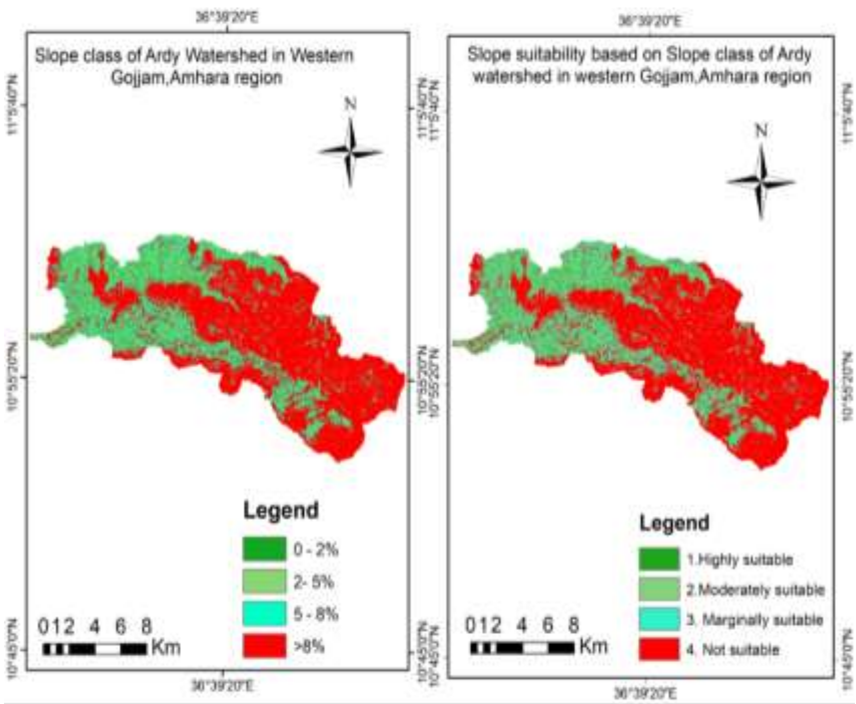
Slope suitability analysis

Slope is key factor affecting land suitability for irrigation, particularly surface irrigation. According to the slope classification result, the land having slope range below 2% was classified as highly suitable while the slope range > 8% categorized as non-suitable class for surface irrigation. Based on the four slope classes (S1, S2, S3 and N), the suitability of the study area for the development of surface irrigation system is shown in figure 4 1and the area coverage of the suitability classes are presented in table 16.

The slope suitability result indicates that 4.67% (1013.464ha) of the land is highly suitable, 19.17% (4166.163ha) is moderately suitable, 15.72% (3416.15Ha) is marginally suitable and 60.44 %(13132.17ha) is not suitable for surface irrigation development. More than half of the watershed land area is not suitable for surface irrigation in terms of slope. However, only about a quarter of the watershed the area (24%) is highly and moderately suitable that is assumed to be readily available with minor adjustments to the surface irrigation.

Table 16: Slope suitability classes for surface irrigation

Slope range	Area coverage(Ha)	Area coverage (%)	Suitability classes
0-2	1013.464	4.67	S1
2-5	4166.163	19.17	S2
5-8	3416.15	15.72	S3
>8	13132.17	60.44	S4



(a) (b)

Figure 9. (a) Reclassified slope and (b) suitability class map

Soil suitability Analysis

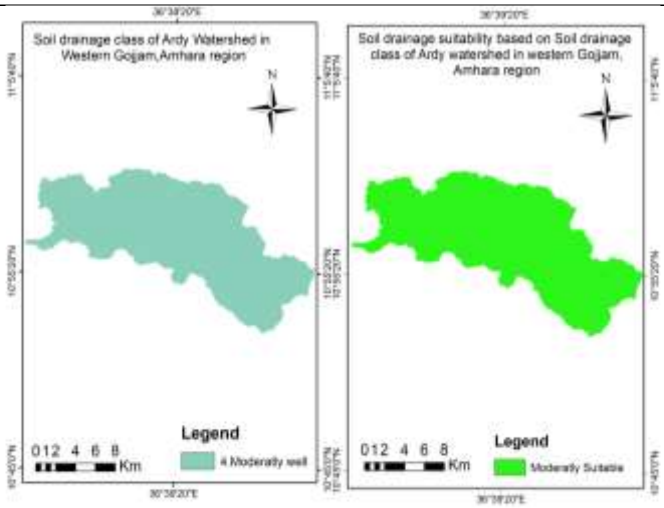
The land suitability of the watershed with regard to soil has been, established by assessment of the soil suitability parameters; soil texture, soil depth and soil drainage are the major physical factors of soil, which were very important for assessment of irrigation potential of the watershed. They affect the root growth of plant, infiltration of water into soil and the production of the crops. For this soil suitability assessment of irrigation the soil mapping unit of this area was used for analysis. The physical property of the soil mapping units such as soil depth, soil texture and soil drainage that were obtained from UNISCO/FAO guideline were used for interpretation and analysis. These physical properties of the soil were assessed independently to determine the irrigation potential of the land.

Soil drainage suitability analysis

Drainage controls continuous movement of water and salt through the soil profile. According to FAO(1997),that the soil drainage condition of a specific area were classified into; well drained, moderately drained, poorly drained and imperfectly drained depending on soil depth and texture. The figure 17 shows that the watershed was characterized by moderately drained soils. The result of the soil drainage suitability in table 17 shows that 100% of the soil which covers an area of 21714.27 ha was moderately suitable (S2).

Table 17. Soil drainage suitability for surface irrigation

Soil drainage category	Area coverage(ha)	Area coverage (%)	Suitability class
Moderately drain	21714.27	100	S2



(a) (b)

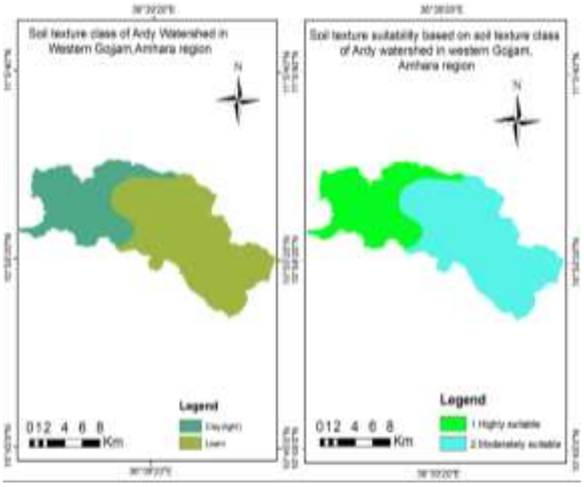
Figure 10. (a) Reclassified class and (b) suitability class map

Soil texture suitability Analysis

The soil texture of the study area was classified into clay light (C) and loam (L). The result of soil texture suitability in table 18 and in figure 11 shows that 64.89% of the soil which covers an area of 14090.35 ha was highly suitable, and 35.11%of the soil which covers an area of 7624.551ha were moderately suitable. The result of soil texture suitability indicates that there is no land categorized as marginally and not suitable in study area for surface irrigation assessment.

Table 18: Soil texture suitability for surface irrigation

Soil texture	Area coverage(ha)	Area coverage (%)	Suitability class
Clay(light)	14090.35	64.89	S1
loam	7624.55	35.11	S2



(a) (b)

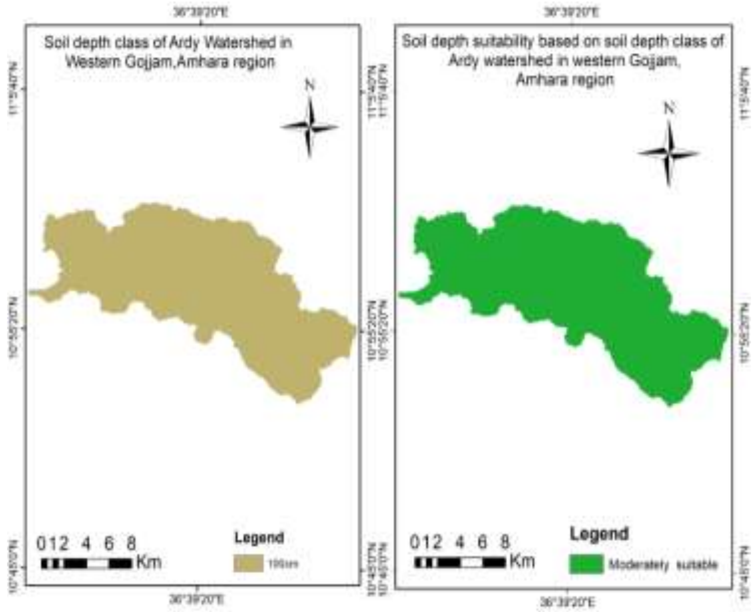
Figure 11. (a) Reclassified class and (b) suitability class map

Soil depth suitability analysis

Soil depth was considered as one of the major factors that determine the selection of land for surface irrigation potential in the study area. It determines the root growth as well as presence of volume of water and air in the soil. The soil depth of the study area was 100cm which covers 100% of the study area. The result of soil depth suitability analysis in table 19 and figure 12 shows that 100% of the soil which covers 21700ha was moderately suitable.

Table 19. Soil depth suitability for surface irrigation

Soil depth	Area coverage(ha)	Area coverage (%)	Suitability class
50-100	21714.27	100	S1



(a) (b

Figure 12. (a) Reclassified class and (b) suitability class map

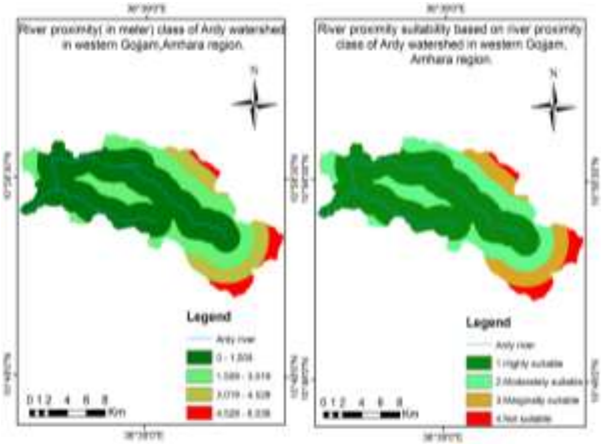
River Proximity Suitability Analysis (Distance from Water Source)

To identify irrigable land close to the water supply (rivers), straight-line (Euclidean) distance from watershed outlets was calculated using river network and DEM (30m*30m) and reclassified. The spatial proximities to water sources were computed using spatial analysis reclassify tools of respective GIS layers.

The result of river proximity suitability analysis in table 20 and figure 13 shows that 67.00% of land which covers 14560.4ha was highly suitable (highly close to the river), 26.60% of land which covers 5779.913ha was moderately suitable (moderately close to river), 6.12% of land which covers 1330.869ha was marginally suitable (marginally close to river), and 0.28% of the land which covers 61.8609ha was not suitable (not close to river).

Table 20: River proximity suitability for surface irrigation

Proximity to water(m)	Area coverage(ha)	Area coverage (%)	Suitability class
0-1,509	14560.4	67.00	S1
1,509-3,019	5779.913	26.60	S2
3,019-4,528	1330.869	6.12	S3
4,528-6,038	61.8609	0.28	N



(a) (b)

Figure 13: (a) Reclassified class and (b) suitability class map

Land use land cover suitability analysis

The land use land cover classified by supervised classification in the watershed dominantly included agriculture, grassland, and shrub land, and forest, water body and built up. After the classification the accuracy assessment would be done. The accuracy assessment tells us how effectively the pixels were sampled correctly to respective LULC classes. The overall classification accuracy which is the ratio of the total number of correctly classified pixels to the total number of reference pixels was 86.4% and the kappa coefficient was 0.86. This showed that the classification was accurate enough to use. For LULC suitability analysis the reclassification of watershed was done by using Arc tool box in GIS (spatial analyst tool →reclass →reclassify) these agriculture as highly suitable, grassland as moderately suitable, shurbland as marginally suitable and water body, built up and forest as not suitable. The result of land use land use suitability analysis in table 3 6 and figure 3 6 shows that 32.53% of land which covers an area of 7065.63ha was highly suitable, 12.80%of land which covers an area of 2779.92ha was moderately suitable, 25.16%of land which covers an area of 3464.8 ha was marginally suitable, whereas 29.51%of land which covers an area of 6410.05ha was categorized as not suitable for surface irrigation potential assessment.

Table 21. Land use and land cover suitability for surface irrigation

Land use land cover class	Area coverage(ha)	Area coverage (%)	Suitability class
Agriculture	7065.63	32.53	S1
grassland	2779.92	12.80	S2
shurbland	3464.8	25.16	S3
Waterbody/built up/forest	6410.05	29.51	N

Water availability

Water availability assessment has been analyzed from the simulated stream flow, realizing through Arc SWAT model in each sub watershed. The observed flow data were used for calibration and validation by considering sensitivity parameters using SWAT CUP Sufi_2 software. The water availability assessment understands the potential of irrigation water supply in each sub basin obtained from SWAT simulated output. Table 22 shows that the minimum monthly simulated flow that used to compare with gross irrigation requirements of the whole crops to identify potential suitable command area in the watershed.

Table 22: Minimum monthly simulated flow (m3/sec)

sub watersheds	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.17	0.06	0.02	0.02	0.15	1.14	1.97	3.00	2.24	1.53	0.81	0.37
2	0.81	0.27	0.12	0.08	0.77	7.35	12.00	18.46	12.88	8.72	4.24	1.88

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3	1.51	0.53	0.20	0.13	1.16	10.65	18.40	28.46	20.49	14.66	7.52	3.51
4	0.60	0.23	0.08	0.05	0.38	2.89	5.78	8.61	6.56	4.79	4.79	1.35
5	0.35	0.10	0.05	0.05	0.48	4.90	7.28	11.38	7.58	4.88	2.07	0.82

Sensitivity analysis

Sensitive analysis was carried out to identify which model parameter is most important or sensitive. Flow sensitivity analysis was carried out for a period of 9 years, which includes two years of warm-up period (from January1, 1996 to December 31, 1997). Where the outlet of the watershed found in flow calibration with the output of 10 parameters were reported as sensitive in different degree of sensitivity for flow. Among these 10 parameters most of the parameters were grouped under a high sensitivity range. Sensitive parameters considered for calibration were SCS runoff curve number (CN2),base flow alpha factor (Alpha-BF), Ground water delay(GW_Delay), Threshold depth of water in the shallow aquifer required for return flow to occur(QMQMN), Moist soil density(SOL_BD), soil evaporation compensation factor (ESCO), Available water capacity(SOL_AWC), saturated hydraulic conductivity(soil_k), Ground water "revap" coefficient (GW_REVAP), and Manning's "n''value for the main channel(CH_N2). Among these, the surface runoff parameter curve number (CN2) was the most sensitive over the other parameters, because it depend on many factors like land use and soil type (permeability and texture).

Table 23: Sensitive parameters and ranking

Parameters	Range	Fitted value	T-stat	P-value	Rank
CN2	0.185-0.19	0.185	-82.03	0.00	1
GW_DELAY	100-100.01	100.00	-1.69	0.09	2
SOL_BD	1.99-2	1.994	1.22	0.44	3
SOL_AWC	0.999-1	0.999	0.89	0.37	4
GWQMIN	24.57-25	24.887	-0.78	0.46	5
SOL_K	1000-1100	1023.7	-0.64	0.52	6
ALPHA_BF	0.88-0.91	0.907	-0.48	0.63	7
ESCO	1-1.02	1.019	0.39	0.69	8
CH_N2	0.09-0.1	0.093	-0.09	0.92	9
GW_REVAP	(-0.2)- (-0.15)	-0.165	-0.04	0.96	10

The result of the sensitivity analysis showed that curve number (CN2), GW_DELAY, SOL_BD and SOL_AWC are identified as highly sensitive parameters .The result that analysis was found that curve number (CN2) is the most important factor influencing stream flow in the Ardy watershed.

SWAT Model Calibration and Validation

The calibration and validation of the model was conducted by using SWAT_CUP model. The SWAT model calibrated and validated stream flow data of Ardy River from the years 1998-2001 and 2002-2004 respectively. The model performance measures which have been used in this model were the coefficient determination (R2), Nash-Sutcliffe (NSE) and Percent bias (PBIAS). The coefficient determination (R2), Nash-Sutcliffe (NSE) and Percent bias (PBIAS) result shows that R2=0.8, NSE=0.75 and PBIAS=0.3% for calibration and R2=0.73, NSE=0.7 and PBIAS=7.8 % for validation respectively. The resulted value of coefficient of determination (R2),Nash-Sutcliffe(NSE) and Percent bias (PBIAS) values fulfilled the statistical model performance criteria R2>0.6 ,NSE>0.5 and PBIAS>±15. The statistical model performance results value were shown in table 24.

Table 24: Values of R2, NSE and PBIAS from calibration and validation model.

Period	Values		
	R^2	NSE	PBIAS
Calibration(1998-2001)	0.8	0.75	0.3
Validation(2002-2004)	0.73	0.71	7.8

The observed and simulated comparison results are shown in the figure 3.8 and 3.9 for the calibration and validation model respectively.

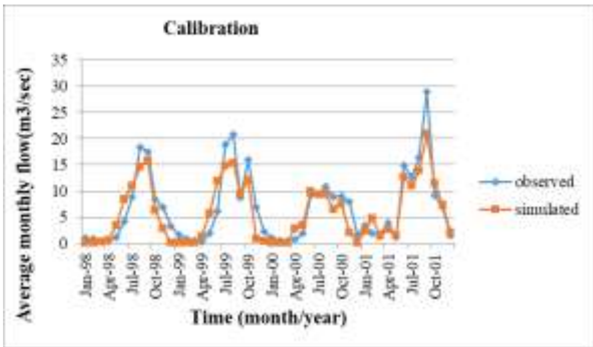

Figure 14. Comparison of observed and simulated discharge for the calibrated model.

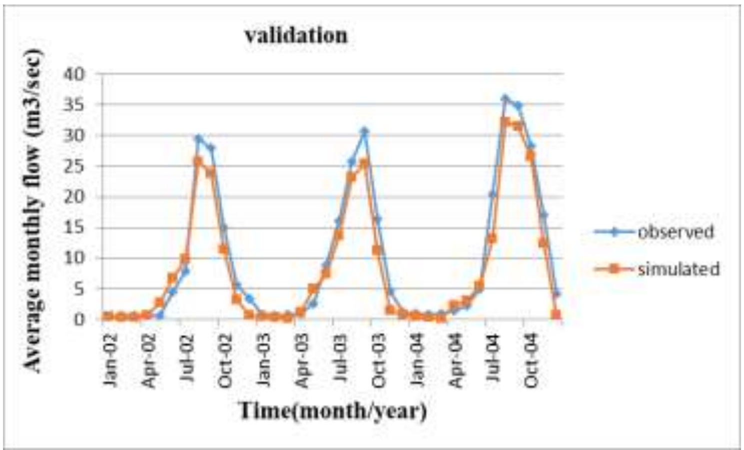

Figure 15: Comparison of observed and simulated discharge for the validated model.

Irrigation Water Requirement

To estimate surface irrigation potential of the watershed the water demand of the whole selected dominant crops (duty) were essential. The irrigation water requirement of the four selected dominant crops such as; wheat, barley, potato and maize in terms of water availability the potential irrigable lands were identified.

Table 25: Scheme water demand of the whole major crops in L/s/ha

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
1. Spring Wheat	111.8	99.9	29.9	0	0	0	0	0	0	0	22.8	56.4
2. Maize (Grain)	117.5	96.3	19.7	0	0	0	0	0	0	0	23.6	76.9
3. Barley	112.4	78.8	7.1	0	0	0	0	0	0	0	27.6	96.1
4. Potato	112.8	105.4	49.6	0	0	0	0	0	0	0	38.4	78.1
Net scheme irr.req.												
in mm/day	3.7	3.3	0.8	0	0	0	0	0	0	0	0.9	2.4
in mm/month	113.3	93.7	24	0	0	0	0	0	0	0	26.7	75.7
in l/s/h	0.42	0.39	0.09	0	0	0	0	0	0	0	0.1	0.28
Irrigated area (% of total area)	100	100	100	0	0	0	0	0	0	0	100	100
Irr.req. for actual area (l/s/h)	0.42	0.39	0.09	0	0	0	0	0	0	0	0.1	0.28

Table 26: Monthly Net Scheme irrigation requirement for whole major crops in L/s/ha

	Months												
Type crops	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Wheat,Maize,Barley and Potato	0.42	0.39	0.09	0	0	0	0	0	0	0	0.1	0.28	1.28

From table 26 the selected dominant crops (wheat, barley, potato and maize), in the month of January the highest net scheme irrigation requirement of 0.42L/s/ha (0.00042m^3/s/ha) has needed by crops which means in one hector of crops 0.00042m^3/s of irrigation water needed and in the month of march the minimum

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net scheme irrigation requirement of 0.09L/s/ha (0.00009m^3/s/ha) has needed by crops which means in one hector of crops 0.00022m^3/s of irrigation water was needed.

CONCLUSION AND RECOMMENDATION

Conclusion

Surface irrigation suitability was analyzed by considering slope, soil texture, soil depth, soil drainage, land use land cover and surface water availability to compare with gross irrigation requirement and to get critical command area. Surface irrigation land suitability analysis showed that, 23.84% of slope, 93.6%of River proximity, 45.33% land use land cover, 100% of texture was identified in the range of highly and moderately suitable, 100% of soil drainage and 100% of soil depth of the study area was categorized as moderately suitable for surface irrigation. Based on the factors which were considered for land suitability slope was the most important factor in terms of determining the overall suitable land. Based on the result of this study for the slope which have >8% (60.44 %)of area, Land leveling or soil conservation works have to be implemented to break the surface slope and to make it safe for surface irrigation. The overall suitability of the area for surface irrigation, about 7886.2ha (38%) were in the range of highly to moderately suitable, whereas 6345.41ha (30.73%) were grouped as not suitable for surface irrigation development.

Surface irrigation potential was identified by comparing available stream flow and gross irrigation water requirement. The annual average stream flow simulated in the watershed was 6.5m^3/s and gross irrigation water requirement of the major crops shows that 7.07m^3/s for wheat, 6m3/s for barley, 4.04m^3/s for maize and 3.03m^3/s for potato. The gross irrigation requirements of major crop were greater than available stream flow. As the available stream flow was less than gross irrigation requirements, the suitable land of 6252.52ha was taken as potentially suitable. This implies that surface irrigation potential of the watershed was limited by water to be irrigated along them. The result showed that total average annual flow of 6.5m3/s was available to irrigate the total irrigation potential suitable land of 6252.52ha in the watershed.

Recommendations

Irrigation is considered as an important investment for improving rural income through increased agricultural production. However this can be achieved, by assessing available land water resources for irrigation. Based on research out put the following recommendations were drawn for further management of the watershed.

- In this research the factors for land suitability analysis was only slope, soil texture, soil depth, soil drainage, distance from water source, land use land cover. To get best and reliable irrigable land for sustainable irrigation development in the watershed, the chemical properties of the soil should be considered. In addition water quality, environmental, socio-economic issues should be assessed for further irrigation development.
- A surface irrigation land suitability analysis result indicates that only 38 %(7886.16ha) of the study area is suitable for surface irrigation. But only 30.28 %(6252.52ha) was potential suitable land in the study area. So, sprinkler and drip irrigation methods should be carried out to increase the land area to be irrigated.
- In this study the available flow in the watershed was not satisfy the gross irrigation requirement of crops in the dry season, so for sustainable irrigation development water storage structures and extraction of ground water was necessary for growing crops.
- Estimation of irrigation water requirement was conducted by selecting four crops (wheat, barley, potato and maize) only for detail study several crops should select to calculate gross irrigation requirements of crops.
- Based on the result of this study for the slope which have >8% (60.44 %)of area, Land leveling or soil conservation works have to be implemented to break the surface slope and to make it safe for surface irrigation.

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