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Spate Irrigation Potential Assessment for Ethiopian Watershed

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Abstract

In the low lands of Logia sub basin, Ethiopia, because of shortage of rain to fully grow crops, irrigation is an obligation in general and the presence of seasonal rivers flowing in the region in particular makes flood utilization ideal for spate irrigation. The subjects of the present study were to assess the spate irrigation potential of Logiya watershed that has been brought under irrigation on the basis of flood water availability and land suitability. A GIS based technique combined with analytical hierarchy process (AHP) was applied to access the potential of the watershed for spate irrigation development. Potentially suitable sites for spate irrigation development were assessed for Maize, Sorghum and Tomato crops. Spate irrigation area was evaluated based on land use/cover, slope and soil suitability. CROPWAT software was used to estimate the reference crop evapotranspiration, effective rainfall, net irrigation and gross irrigation water requirement. The suitability model developed shows that only 26.15% of the total area falls under marginally to highly suitable categories for spate irrigation development. The Logiya seasonal river flow from July to October was 301.64 Mm^3. However, the annual flood water available from the river was less than the total GIWR by 8.77 Mm^3 during growing period. The surplus water available from the river before July might be stored and used for irrigation during water deficit period during growing seasons.

Keywords: ArcGIS, potential assessment, suitability analysis, spate irrigation

1. Introduction

Ethiopia is the second most populous country in Africa (Awulachew et al., 2005). About 85 percent of which lives in the rural areas depending on subsistence agriculture. Though agriculture is the dominant sector, most of Ethiopia's cultivated land is under rainfed agriculture. Due to lack of water storage and large spatial and temporal variations in rainfall, there is not enough water for most farmers to produce more than one crop per year and hence there are frequent crop failures due to dry spells and droughts which has resulted in a chronic food shortage currently facing the country (Awulachew et al., 2007).

The total potential irrigable land in Ethiopia is estimated to be around 3.7 million hectares. The estimated irrigation potential for Awash River basin is about 134,121 hectares. Out of these, a potential, 30,556 hectares are for small-scale, 24,500 hectares for medium-scale and 79,065 hectares for large-scale development. Even if the country has large potential of land for irrigation, only about 4 to 5% is under irrigation.

To feed an ever increasing population, assessment of all unutilized resource potential of land and water resource in the country is prime importance for planning of sustainable food production in the national as well as regional level. The existing irrigation development in Ethiopia, as compared to the resources potential, is not significant and the contribution of irrigation is not satisfactory.

Substantial amount of studies have already been performed on the subject of irrigation potential based on surface water over the last decade since formal irrigation started in 1960 in Awash basin (Megersa, 2017). When analysis of those studies done on the subject of irrigation potential almost all concerned on surface source of water and this perceptions ignore the fact that one of the world's oldest forms of irrigation practice arose in arid zones and remains a crucial element in the agricultural economies of the country generally known as spate irrigation has hardly received any serious attention from policy makers, technical experts or donors and detail potential is not documented yet (van Steenbergen et al., 2010).

Due to geological setting of Ethiopia no drainage is coming in but flows out radiating in all directions and mean annual specific runoff which is 54.4 BCM (Alamayehu, 2008) has been flow as flash flood along all its basin through arid and semiarid regions which constitute 70% of the total landmass of the country's (Bogale & Shimeles, 2009). Historical record states that in Ethiopia, flash flood occurred in almost all basin which Awash basin is one. Based on hydrological analysis, Awash basin divided in to 21 sub-basins which contribute annual runoff of 900 Mm^3 out of 4.6 Bm^3 annual potential of surface and runoff water of basin (Nigatu, 2006). Destructive flood is occurring at any rainy season in the basin in general and further downstream of Awash basin in particular. To overcome this challenge changing this flood which is unpredictable and destructive in to something that is useful is the last option to alleviate the moisture stress for spate irrigation as well as flood control in low land area where rapid flood putting huge pressure on the natural resource (Daniel et al., 2014).

Limited research has been done on the assessment of irrigable land for spate irrigation to enable irrigated agriculture practice in Ethiopia. This study contributed by incorporating the following points: (1) Assessment of land suitability for spate irrigation; (2) Assessment of Spate irrigation water requirement for Logia sub basin; (3) produce a spate irrigation suitability map using GIS. The results from this study would help local decision makers and stakeholders on the expansion of small-scale irrigated agriculture in the region. Policy makers need to consider spate irrigation options in their agriculture development programs.

1.1 Problem Statement

The understanding of many people is that floods can be one of the most destructive force of nature will continue to cause serious economic and environmental losses. In Awash basin, When an example looks back in to history and analysis from recent memory is the flood that had been caused in 2006 in the eastern catchment of Awash basin, Dire Dawa administrative council which caused deaths of 256 people, 244 missing and more than 9956 people displaced (Billi et al., 2015). The other is Tributaries of lower Awash basin from wollo high lands such as Mille and Logia seasonal rivers flows have also caused severe impacts on human lives and property especially in the area between Dubti and Assaita woreda of Afar regional state lower Awash basin. But flood is not always hazard as no one could imagine that this barren land would ever show signs of life if there is no flood. In addition to these, if this destructive flood is managed it is possible to change in to something which is useful and productive especially for spate irrigation since irrigation has had direct benefits in terms of production and incomes, and indirect benefits in terms of reduced incidence of downstream flood damage (FAO, 2010). On the other hand Tesfay (2002) state that flood and famine is the twin and alternative curses, flood is a blessing in disguise; thus, famines may be effectively prevented by floodwater. In order to plan the development of this water resource carefully, especially for agriculture which is by far the largest user of water, an assessment of irrigation potential becomes a very timely and crucial issue (FAO, 1995). As Daniel et al. (2014) state the Afar region has one of the highest spate irrigation potential and practices in Ethiopia as the runoff generated from the highlands of Amhara and Tigray, however, detail assessment of the potential of spate irrigation in Afar as general and lower Awash basin of Afar regional state in particular is not carried out to date. Rational assessment is crucial to know the potential of spate irrigation in the Logiya sub basin of Awash, Afar national regional state using Logia seasonal flood. The principal objective of this study is both to identify potential areas suitable for spate irrigation and to quantify the available Logia flood water potential for spate irrigation by using GIS techniques.

2. Materials and Methods

2.1 Study Area

The logia sub basin of Awash basin considered for this study are geographically setup in the arid lowlands in the north-eastern parts of Ethiopia in great rift valley between 11°35′ to 12°5′ N latitude and 39°35′ to 41°5′ E longitude (Figure 1). The study area is dominated by flat lowland areas with mountainous boundaries with an elevation varying from 362 m to 3453 m. The annual rainfall varies from 176.2 mm to 344.1 mm. The mean annual minimum and maximum temperatures ranges between 16 °C and 38.0 °C and month of June had the highest temperature while December extremely lowest temperature. In Ethiopia there are five agro-ecological zones classification; very cold (Wurch), cold (Dega), sub-moist cool (Weina-dega), sub-moist warm (Kolla) and dry-hot (Bereha). The study area is classified as the dry-hot (Bereha)-ecological Zone. The long term monthly average rainfall for the study area has bimodal rainfall pattern with peaks in August and July. The soil in the study area is dominated by Fluvisols, Leptosols and Regosols (Halcrow, 1989). Fluvisols are found in plains and gentle slopes, Leptosols are mainly found around hills and steep slopes. The area under irrigation is dominated by Regosols soils.

2.2 Data Used

Necessary input data used in this study were collected from governmental organizations and online sources. The meteorological data; precipitation, maximum and minimum air temperature, relative humidity, wind speed and Sunshine duration were obtained from the Ethiopian National Meteorological Agency (NMA) for nearby metrological stations (*i.e.*, Logiya, Dubti, Chifra and Ambasel). The time series Hydrological data (1985-2015) and spatial data; digital topographic map; digital soil map, land use land cover map (LULC has been collected from ministry of water, irrigation and electricity (MoWIE). Digital elevation model (DEM), 30 × 30 m, was obtained from United States Geological Survey (USGS). Data in relation to Crop types and cropping patterns were obtained from the Ministry of Agriculture.

2.3 Methodology

2.3.1 Physical Land Parameters for Spate Irrigation Suitability

The methodology used to evaluate land suitability for potential spate irrigation was done following the standard FAO guidelines (FAO, 1997). The suitability of each factors were first analyzed separately and finally overall suitability was obtained using weighted overlay analysis in GIS environment in a way that manifests the potential of spate irrigation in Logiya sub basin area.

The main irrigation land suitability factors undertaken were slope, soil texture, soil type, soil depth, drainage suitability, and land use land cover (Figure 2(a)-(f)).

The Slope suitability map of the study area which were derived from the 30 m DEM (Figure 2a) was classified based on the FAO guideline (Figure 2(g)).The four suitability criteria were S1 = 0-2% , S2 = 2-5% , S3 = 5-8% and N > 8% representing highly suitable, moderately suitable, marginally suitable and not suitable for spate irrigation, respectively.

Soil texture, soil drainage, soil depth and soil type are the major physical properties of soil which were used for evaluation of irrigation potential of the basin. The rasterized soil map were reclassified based on these factors.

Weighted overlay analysis for all factors were determined using an overlay tool in ArcGIS 10.3. The land suitability was classified based on an overall score value from 1 to 9 such as (1) highly suitable land (score9); (2) moderately suitable land (score 6); (3) marginally suitable land (score 3); and (4) least suitable land (scour1).

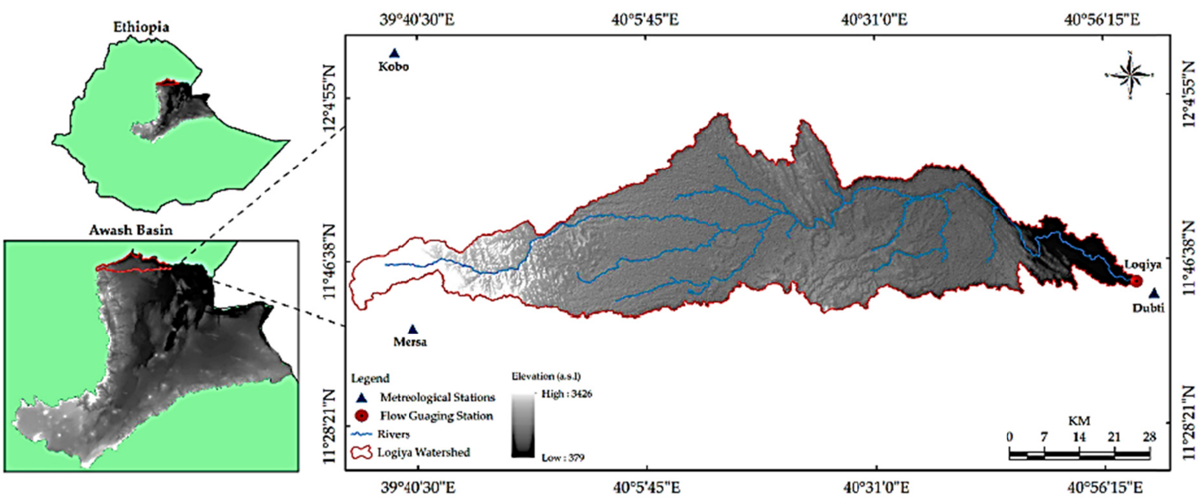

Figure 1. Locations of Logiya watershed with Meteorological and flow gauging stations

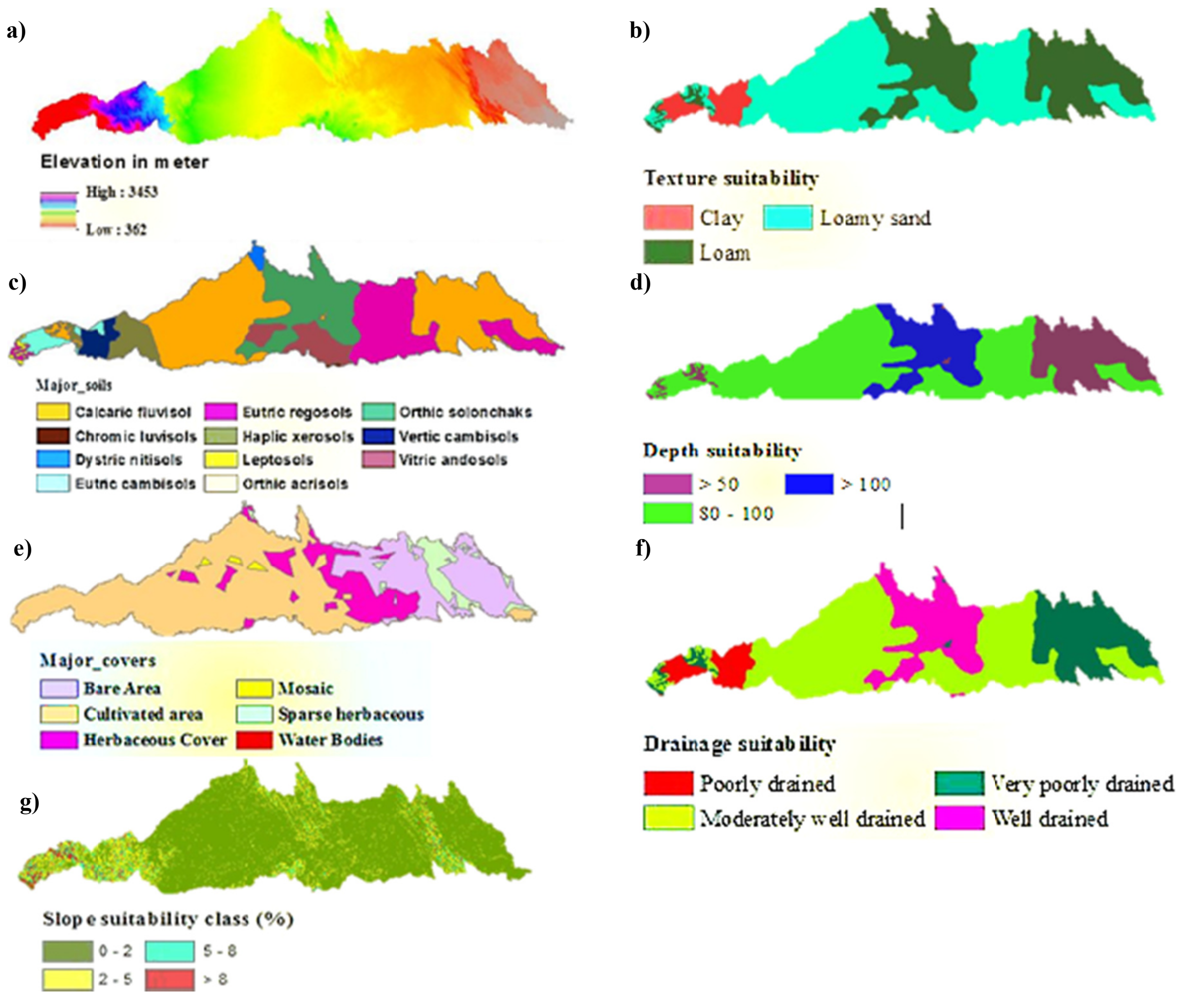

Figure 2. Thematic maps of the Logiya watershed

Score values different from 9, 6, 3, 1 were not assigned for any cell, this indicates that the particular cell (*i.e.*, score) is delimited from spate irrigation, thus should be eliminated from the evaluation. LULC map (Figure 2(e)) of the watershed was derived from satellite image. The LULC type was reclassified into four suitability classes and given value from S1 to N represents very suitable to unsuitable.

2.3.2 Assessment of Irrigation Water Requirement

Available flood water on the study area was evaluated by using stream flow discharge obtained from ministry of water, irrigation and electric city from period of 1990-2010. This period was chosen because of its continuous time series data with less missed information.

The available flood water was estimated for the whole crop growth period. Gross irrigation demand for three major crops (*i.e.*, Maize Sorghum and tomato) and the average annual monthly stream flow was evaluated and compared.

Crop evapotranspiration (ET_c) was calculated by multiplying the crop coefficient (KC) values at each growth stage of the specific crop by the corresponding reference crop evapotranspiration (ET_o) (FAO, 1998) for Maize Sorghum and tomato crops in CROPWAT.8.O environment.

Using the calculated Crop evapotranspiration (ETc) and effective rainfall (Peff) values, the irrigation water requirement (IWR) was estimated Equation (1). Net irrigation requirement (NIWR) for major crops were calculated using the identified potential irrigable site command area and the calculated irrigation water requirement (IWR) (Equation 2). The gross irrigation water requirement (GIWR) of crops at the were estimated by considering application efficiency (*Ea*) of 50% and water conveyance efficiency (*Ec*) of 90% for spate irrigation (Smith, 2000; FAO, 2001) (Equations 3):

$$IWR = ET_C - P_{effective};\ P_e = P(1 - C) \quad (1)$$

$$NIWR = \frac{\sum IWR_i \times A_i}{A} \quad (2)$$

$$GIWR = \frac{1}{E}(NIWR \times A_{Crop}) \quad (3)$$

Where,

NIWR and GIWR are net and gross irrigation water requirement (mm), respectively; ETc = crop evapotranspiration (mm day^{-1}); Pef = effective precipitation (mm day^{-1}); P = daily rainfall (mm day^{-1}); C = constant equal to 0.20; E = irrigation efficiency in fraction.

3. Results and Discussion

3.1 Land Suitability for Spate Irrigation

Slope: The slope analysis result reveled that about 88.2% of the total study area was classified as highly to marginally suitable for spate irrigation (Figure 2g). The remaining 11.8% of the sub-basin area having slope of greater than 8%, which is marginally to permanently not suitable for spate irrigation. According to FAO (1999) suitability classification, most of the area of the Logiya sub-basin was falls below 8%, which is in suitable range of slop classification for spate irrigation.

Soil type and depth: The major soil groups recognized in the study area were Calcaric fluvisol (45.8%), Orthic solonchaks (16%) and Orthic solonchaks (6.5%) (Figure 2(c)). Soil depth was among the significant physical soil parameters used to assess soil suitability for surface irrigation development. Soil depth was inferred from geomorphology and the soil map of FAO, 1991. The soil depth in the sub-basin varied from < 30 to > 120 cm. Further, the soil depth was reclassified into four classes; 30-50, 50-80, 80-100 and > 120 and soil depth of the study area was analysis in Arc GIS 10.41 version (Figure 2(d)). From Figure 2(c) and Table 1, it is manifested that most of the eastern and central part of the Logiya sub-basin soil is categorized as highly to moderately suitable (97%) and the areas with soil type Eutric cambisols, Leptosols and Orthic acrisols are classified as not a suitable class for the use of spate irrigation development.

As shown in Figure 2(d), based on soil depth suitability 138905.9 ha (41.6%) is highly suitable, the area 166171.9 ha (49.8%) is marginally suitable and the area 28541 ha (8.5%) is not suitable class.

Table 1. Soil suitability characteristics and area covered in Logiya sub-Basin

SNo	Soil type	Soil texture	Soil depth	Soil drainage	Suitability class	Area	
						ha	%
1	Calcaric fluvisol	loamy sand	100	Well	S2	159854	45.83
2	Chromic luvisols	Loam	110	Well	S1	418	0.12
3	Dystric nitisols	loam	110	Well	S1	3009	0.86
4	Eutric cambisols	Clay	100	Not-drained	N	8587	2.46
5	Eutric regosols	loamy sand	100	Imperfect	S2	65833	18.87
6	Haplic xerosols	loamy sand	100	Imperfect	S2	17573	5.04
7	Leptosols	Loam	30	Not-drained	N	1791	0.51
8	Orthic acrisols	clay	100	Not-drained	N	1	0.0003
9	Orthic solonchaks	Loam	110	Well	S1	58796	16.85
10	Vertic cambisols	Clay	100	Poor	S3	10388	2.97
11	Orthic solonchaks	loamy sand	100	Imperfect	S2	22513	6.45

Note. S1 = highly suitable, S2 = moderately suitable and N = conditionally not suitable.

Well-drained soils are characterized under the high suitability rating class and imperfectly drained soils are considered as moderately suitable for surface irrigation development (FAO, 1984) (Figure 3(f)).

Drainage: Soil drainage is one of the most important parameters for spate irrigation potential assessment. In the study area, three soil drainage classes, *i.e.*, well-drained, imperfectly drained and not drained classes were identified based on the FAO (1985) guidelines. The drainage suitability map (Figure 2(f)) and Table 1 show about 63.66 % (222,077 ha) of the area is in the well-drained soil class and (30.36%, 105,919 ha) is categorized under the imperfectly drained class and about (5.98%, 20,767 ha) is classified as not drained.

Overall soil suitability: The overall soil suitability was estimated using the weightage of each factor (slope, soil type, depth and drainage) to obtain potential irrigable sites (Figure 3 and Table 1). The distance of the water supply source from irrigable land was also considered along with these factors for weighted overlay analysis. Once the suitable areas based on slope, soil and land use land cover (LULC) were identified, overlay analysis (using raster calculator in ArcGIS) was done to produce a map layer which showed the suitable areas for spate irrigation based on the combined criteria. The result (Figure3) showed that most of the study area is categorized under not suitable for spate irrigation which covers the area of 242,473.2 ha (73.85%). 24585 ha (7.49%) of the study area classified as marginally suitable for spate irrigation.

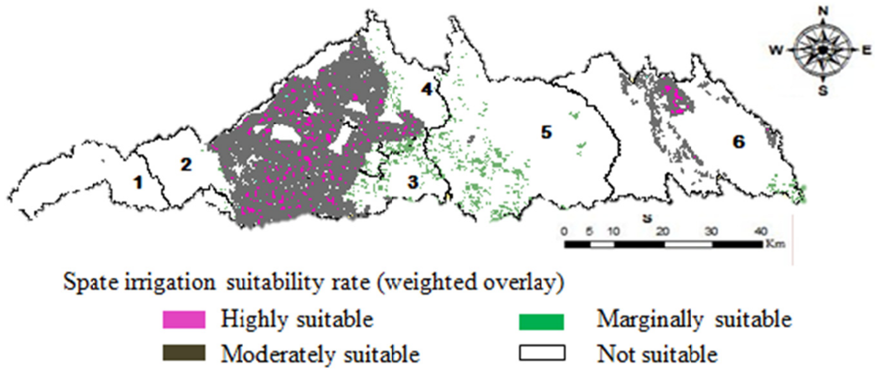

Figure 3. Weighted overlay analysis of the potential of irrigable land in the Logiya sub-basin

20573ha (6.27%) is categorized under moderately suitable for spate irrigation. Highly suitable lands for spate irrigation development are only 12.39% (40681 ha).

The most suitable area for spate irrigation was presented in sub basin no 3 (Table 2) which has been classified based on the three important parameters which are slope, soil and LULC type accordingly. Whereas the most non-suitable part shows at sub watershed no 6, 5 and 1 due to the suitability degree of each parameter as indicated. The overall suitable site for spate irrigation were elaborated in a percentage layout where; S1, S2, S3 and N stands for highly, moderately, marginally and unsuitable class for spate irrigation development respectively as shown in Table 2.

Table 2. Overall suitable land for spate irrigation in the sub watershed level

Sub Watershed	Suitable Class	Suitability Rate	Area (ha)	Area (%)
Sub Watershed 2	Highly Suitable	S1	13315.8	22.9
	Moderately Suitability	S2	6112.9	10.5
	Marginally Suitable	S3	1789.9	3.1
	None Suitable Class	N	36910.4	63.5
	Sub total		58128.9	100.0
Sub Watershed 3	Highly Suitable	S1	15287.9	41.5
	Moderately Suitability	S2	6376.8	17.3
	Marginally Suitable	S3	521.4	1.4
	None Suitable Class	N	14608.4	39.7
	Sub total		36794.4	100.0
Sub Watershed 4	Highly Suitable	S1	7896.8	13.7
	Moderately Suitability	S2	3460.9	6.0
	Marginally Suitable	S3	3277.3	5.7
	None Suitable Class	N	43066.3	74.6
	Sub total		57701.4	100.0
Sub Watershed 5	Highly Suitable	S1	35.9	0.0
	Moderately Suitability	S2	16.7	0.0
	Marginally Suitable	S3	6144.4	6.5
	None Suitable Class	N	88856.0	93.5
	Sub total		95053.0	100.0
Sub Watershed 6	Highly Suitable	S1	3134.9	3.6
	Moderately Suitability	S2	1444.5	1.7
	Marginally Suitable	S3	713.8	0.8
	None Suitable Class	N	80647.0	93.8
	Sub total		85940.3	100.0
	Grand Total		328312.2	100.0

3.2 Assessment of Flood Water Availability and Irrigation Requirement

Average annual monthly stream flow, maximum and minimum flow was evaluated. Available flood water was estimated after some percentage water released for ecological purpose (Table 3 and Table 4). The mean annual flow of Logiya seasonal flow is 48.5 Mm^3 before 25% of ecological purpose is not released and 36.4 Mm^3 after ecological purpose is released. The flow of the river is highly seasonal and 85% of the flow occurs during the months of June up to September. According to the discharge analysis, mean flow in each month from July to September were estimated to be 7.7 m^3/s, 12.8 m^3/s, 12.3 m^3/s and 6.6 m^3/s respectively. The study area receives total average annual rainfall of 344 mm. The effective rainfall was calculated by CROPWAT model using the average recorded rainfall data at four climate gauging stations (Figure 4).

Table 3. Mean, max, and min monthly flow of Logia River at gauged station before 25% released for ecological purpose

Flow	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Max flow (m^3/s)	2.2	0.7	28	145	16.2	0.6	160	269	258	139	0	0.8	1020
Av. flow (m^3/s)	0.1	0	1.3	6.9	0.8	0	7.7	12.8	12.3	6.6	0	0	48.5
Min flow (m^3/s)	0	0	0	0	0	0	0	0.6	0	0	0	0	0.6

Table 4. Mean, max, and min annual monthly flow of Logiya flood River at gauged station after 25% released for ecological purpose

Flow	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Max flow (m^3/s)	1.7	0.5	20.9	108.8	12.2	0.5	120.0	202.1	193.8	104.0	0.0	0.6	764.9
Av. flow (m^3/s)	0.1	0.0	1.0	5.2	0.6	0.0	5.8	9.6	9.2	5.0	0.0	0.0	36.4
Min flow (m^3/s)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.5

The highest effective rainfall during irrigation time was at Mersa station which varied from 4.8 mm during October and 98 mm during August at Mersa Climatic Stations and the lowest is found in Dubti climatic station which varied from 0.7 mm during October and 74 mm during August. Crop evapotranspiration (ETc) was calculated from CROPWAT8.0 model using monthly average value of ETo and crop coefficient for each of the crop Maize, Sorghum and Tomato at Dubti, Logia, Chifra and Mersa climatic stations. Crop water requirements of selected crops grown in the area were calculated assuming mono cropping pattern in the area. The ETc was calculated using the monthly average value of ET0 and the crop coefficient for maize, sorghum and tomato crops.

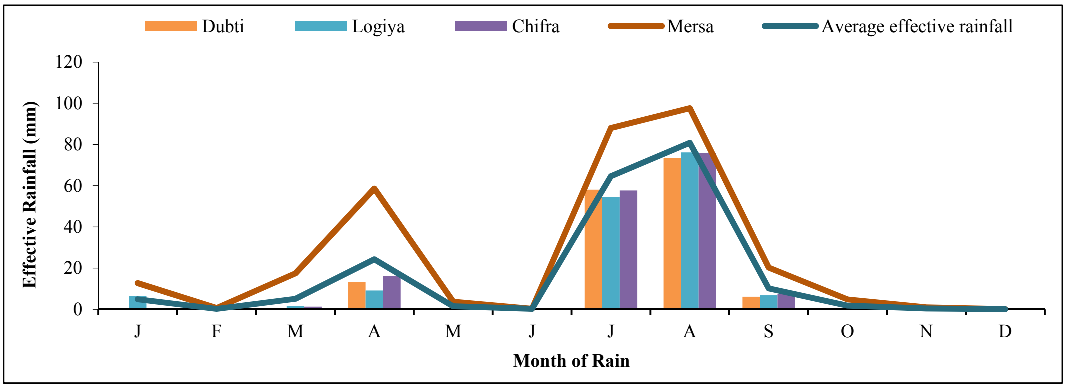

Figure 4. Effective Rainfall at Logiya sub basin gauging Stations

Calculated values of ETc for Maize, Sorghum and Tomato crops and effective rainfall at Logiya varied from 92.8 to 154.6 mm and 47.5 to 128.1 mm 85.3 to 150.5 mm and 0.6 to 76.2 mm respectively. Similarly, the values at Chifra station varied from 104.9 to 171.1 mm, 52.1 to 142.3 mm, 93.6 to 117 mm and 1.2 to 75.9 mm respectively (Figure 5(a)-(b)). The ETc for all crops increased from the minimum value in July to the maximum value during August and September and subsequently decrease till October at all the stations. ETc Tomato crop increased from the minimum value in January to the maximum value during April and subsequently decreased till May. The maximum value of ETc was higher for Maize crop as compared to Sorghum and Tomato crops and Sorghum crop does not irrigation water in the month of July as effective rain fall was greater than ETc. The highest and the lowest values of effective rainfall were during October and August in all the stations respectively. The variations of values of ETc and effective rain fall at all climatic stations are shown in Figure 5. Crop evapotranspiration for both the crops at both the climatic stations was more than the effective rainfall.

The effective rainfall was not sufficient to meet the crop water requirements. Therefore, irrigation was needed in the study area.

The NIR and GIWR from the weekly irrigation schedule for each of the crops for each of the stations were estimated using CROPWAT software (Figure 5(c)-(d)).The monthly values of net and gross irrigation requirement in mm is given in (Figure 5(c)-(d)). The mean monthly values of irrigation water demand and water flow available are clearly identified (Table 4). Results revealed that high irrigation demand observed on the month of September (130.08 Mm^3) and lesser demand on the month of July (39.8 Mm^3). Total irrigation water demand for the catchment 310.41 Mm^3 of water was maintained to irrigate the whole irrigable area of 69529.9 ha of land. The Logiya seasonal river flow from July to October was 301.64 Mm^3. However, the annual flood water available from the river was less than the total GIWR by 8.77 Mm^3 during growing period. The surplus water available from the river before July might be stored and used for irrigation during water deficit period during growing seasons.

Table 4. Irrigation potential of Logiya sub-Basin

Spate irrigation potential assessment	Months			
	July	August	September	October
Average irrigation demand (Mm^3)	39.8	70.03	130.08	70.5
Average water available (Mm^3)	60.08	99.45	95.31	46.8

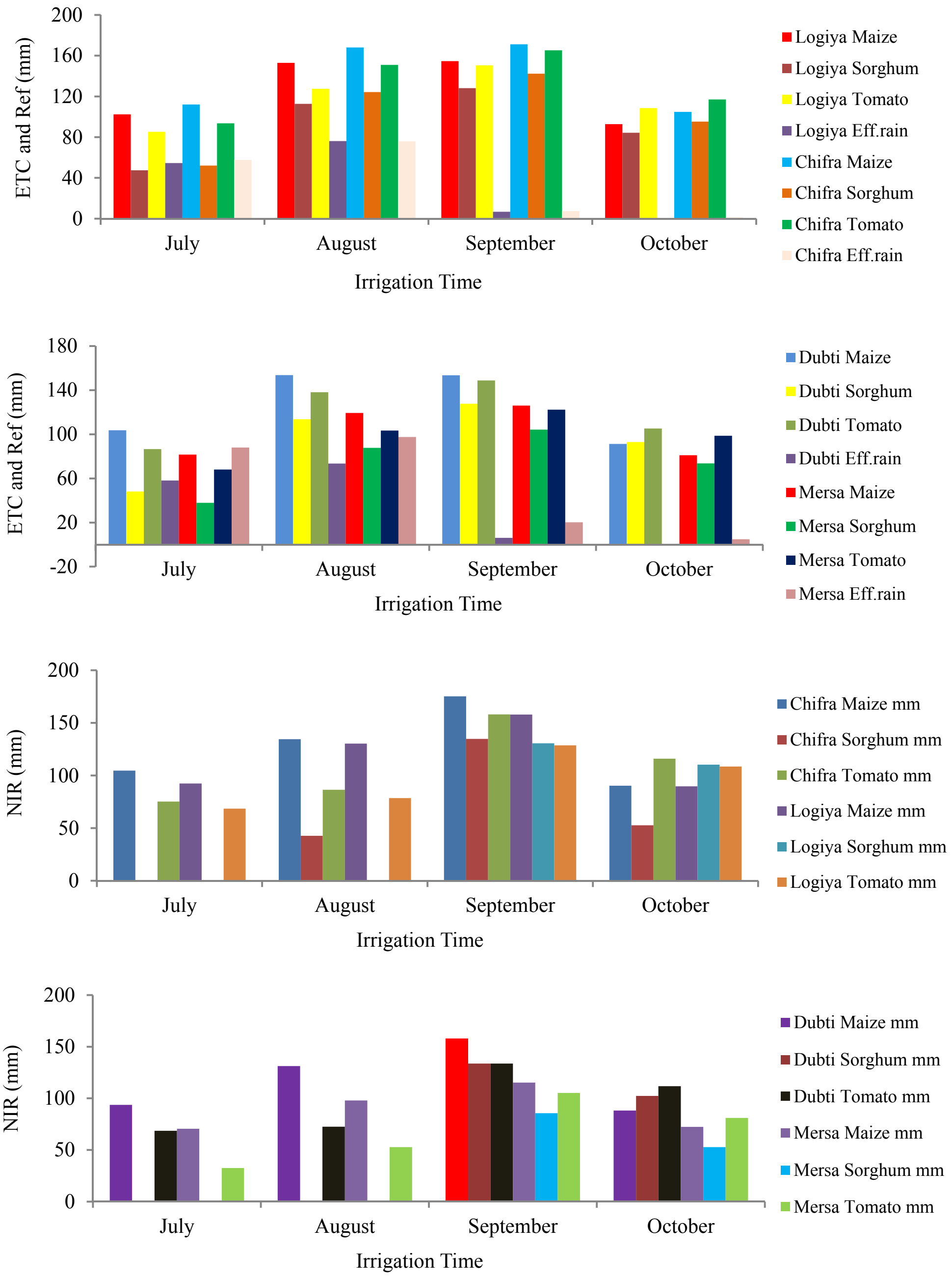

Figure 5. The estimation of (a),(b) ETc (mm) and effective rainfall (mm) and (c),(d) net irrigation water requirement (NIR) at Dubti, Mersa, Chifra and Logiya stations

4. Conclusions

A consistent irrigation water supply will upsurge agricultural productivity, and increase food security level and the rural economy, thus developing irrigation infrastructure is important. However, this can be accomplished by assessing available land and water resources for irrigation. Therefore, the spate irrigation potential of the Logiya watershed was evaluated in this study. The study results showed that about 91.4% and 88.2% of the study area is in the range of highly suitable to marginally suitable for spate irrigation development based on the soil and slope criteria, respectively. The overall suitability using a weighted overlay of the above factors in ArcGIS shows that potentially irrigable land suitable for spate irrigation is about 26.15% of the catchment area. This is expected to reduce further if more factors are considered in the weighted evaluation process and may provide a better estimate of the land potential for spate irrigation. The gross irrigation water requirement (GIWR) of the maize, sorghum and tomato crops was different for the Logiya, Chifra, Dubti and Mersa climatic stations. The Logiya seasonal river flow from July to October was 301.64 Mm^3. However, the annual flood water available from the river was less than the total GIWR by 8.77 Mm^3 during growing period. The surplus water available from the river before July might be stored and used for irrigation during water deficit period during growing seasons.

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