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GIS Based Physical Land Suitability Evaluation of Maize and Sorghum: Case Study Efa Gudina Sub Watershed

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Abstract: To attain optimum productivity of the land and ensure sustainability environmental resource suitable land use decisions are vita. The aim of this paper is to evaluate physical land suitability of maize and sorghum crops using GIS by identify areas with physical constraints for maize and sorghum land uses and the management requirements. The quality rating for each crop type was evaluated against the recommended threshold level for rain fed agriculture. Each crop type was rated for rain fed agriculture suitability following standard FAO guidelines. The findings of the study revealed that, The results of the climate considering, temperature suitability of Efa Gudina watershed show that is highly suitable (S1) for both Maize and Sorghum varieties production under rain fed conditions in all mapping unit. But climate considering, rain fall suitability show that marginally suitable (S3) for Maize and permanently not suitable (N2) for sorghum in all mapping unit. In addition, landscape suitability evaluation showed that, soil mapping units (SMU) 0, 1, 2. 3, 4, & 19 is highly suitable and SMU5 to 13 is marginally suitable (S3) for both rain fed maize and sorghum production. On the other hand, soil mapping units SMU14, 15, 16, 17 & 18 and SMU20, 21, & 22 permanently not suitable (N2) for both maize, and sorghum production due to problems related to sever erosion hazard. Therefore the study suggested that most of the limitations can be improved through improving and sustaining soil management so as to attain the potential suitability of the watershed. However, land suitability for growing crop is not only limited by the selected physical constraints but also socioeconomic factors.

Keywords: Crop Type, Rain Fed Agriculture, Suitability, Land Quality Parameters, Limiting Factor

1. Introduction

Land is a complex and dynamic combination of factors such as geology, topography, hydrology, soil, microclimates and communities of plants and animals that are continually interacting under the influence of climate and people's activities [1]. Land varies from one place to another, hence it should be used based on its capacity to meet human needs and ensure the sustainability of ecosystems [2]. Information on the opportunities and limitations for the use of land will provide basic tools for better crop management practices and guides decisions on optimal utilization of land resources in a sustainable way [3].

Land evaluation is the process of assessing land performance when the land is used for specified purposes under a stated system of management and involves the execution and interpretation of surveys and studies of landforms, soils, climate, vegetation and other aspects of land in order to identify and compare promising kinds of land use in terms applicable to the objectives of the evaluation [4-8] The suitability is a function of crop requirements and land characteristics and it is a measure of how well the qualities of land unit match the requirements of a particular form of land use [7, 9].

Physical land suitability is a prime requisite for land use planning development, since it guides decisions on land utilization type for optimal use of land resources which contributes towards better land management, mitigation of land degradation and designing land use pattern that prevents environmental constraints through isolation of rival land uses [10]. Making effective decisions regarding agricultural land suitability problems are vital to achieve optimum land productivity and ensure environmental sustainability [11-13]. In contrast, the incongruous use of land has resulted in environmental degradation of natural resources that leads to decline in land productivity and deterioration of soil quality for its future use [14]. Thus, the assessment of land suitability is influenced by land capability and other factors such as land quality, proximity to different accesses, land ownership, customers demand and economic values [15].

***Figure 1.** Rain fed farm with maize and sorghum owned by smallholders' farmers in Efa Gudina Sub Watershed, (Field survey, 2020).*

Therefore, the assessment of land suitability classification is useful as some land can be suitable for specific crops and unsuitable for another's; so precision of land utilization types is necessary. It cloud be expressed not only in terms of types of crops productions, but also how this specific crops are produced [4]. Moreover, suitability land evaluation allows us to identify the main limiting factors for the agricultural production and enables decisions makers such as land use planners, land users and agricultural support services to improve as well as develop a crop management able to overcome such constraints, increasing the productivity [4].

Today there is rapid growth of the world's populations, climate change which is in its turn a limiting factor to the arable lands around the world, the need for effective and efficient application of the croplands have been felt more than ever [16, 17]. For instance, in Ethiopia, agriculture particularly cereals (such as; teff, barley, maize, sorghum, oats, millet and wheat) make up 85% and 90% of the total production of field crops and also account for over 90% of input consumption [18]. However, studies shows that, the low productivity remains the major constraint of cereals cultivation, where yields are less than 1ton per ha [19]. Hence, much attention is given to selection of crops, which suits an area the best. The concept of sustainable cereals involves producing quality crops in an environmentally friendly, socially acceptable and economically feasible way [20, 21].

Therefore the objectives of this study was to evaluate physical land suitability of the selected crops using GIS tools which will assist land managers and land use planners to identify areas with physical constraints for a range of nominated land uses. Furthermore to identify the management requirements that will ensure that a particular land use can be sustained without causing significant land quality degradation in Efa Gudina Sub Watershed. The evaluation based on the FAO [9] (framework for land suitability evaluation. This approach gives a useful result that generalizes the constraint of an area for specific kind of land use type. The approach is presented in discretely ranked classes (S1, S2, S3, N1 and N2).

***Table 1.** Framework of land suitability classification.*

Class	Land Description
S1 Highly Suitable	Land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level.
S2 Moderately Suitable	Land having limitations which in aggregate are moderately severe for sustained application of a given use; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on class S1 land.
S3 Marginally Suitable	Land having limitations which in aggregate are severe for sustained application of a given use and will so reduce productivity or benefits, or increases required inputs, that this expenditure will be only marginally justified. With the order Not Suitable, there are normally two classes:
N1 Currently Not Suitable	Land having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost.
N2 Permanently Not suitable	Land having limitations which appear as severe as to preclude any possibilities of successful sustained use of the land in the given manner.

Source: FAO, 1976 and 1981.

2. Methods and Materials

2.1. Description of Efa Gudina Watersheds

Efa Gudina sub watersheds found in Gawo Kebe woreda. The woreda is one of the 11 woredas in Kellem Wollega zone. At present the district has 30 administrative sub divisions or kebeles out of which 28 are Farmers Associations and the remaining two is town. The total area is 974.80 km^2. It is located in the western part of Oromia region at a distance of 594 KM away from Regional capital (i.e. Finfine) and North West part of Kellem Wollega Zone at a distance of 86 Km away from zonal capital (i.e Dambi Dollo town)[22]. Astronomically the Efa Gudina is located between 9° 10'N to 9° 15'N latitude and 34°45'E to 34°55'E longitude.

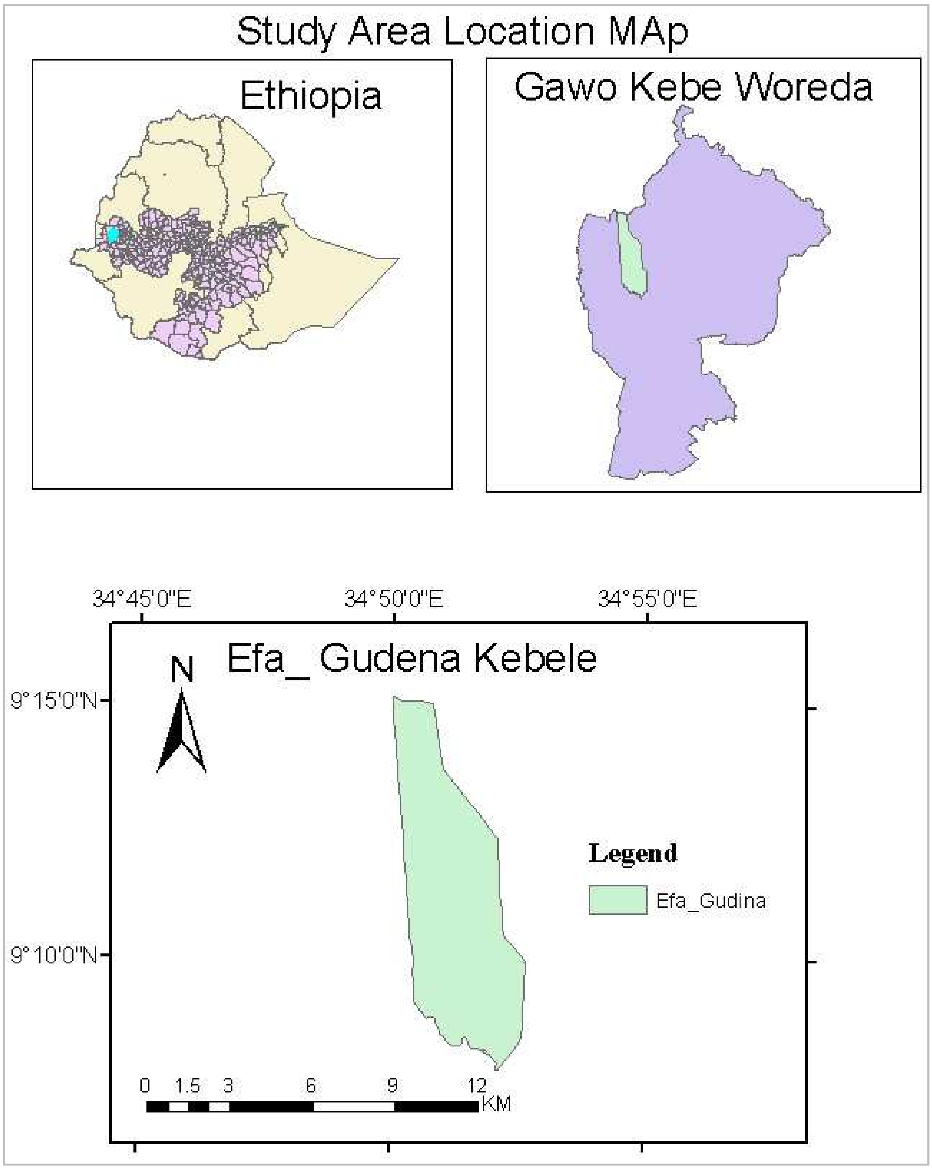

Figure 2. *Map of Efa Gudina watershed.*

Relief, Drainage and Climate: The woreda is characterized by slightly up and down topographic feature. Gara Gawo, Kirite, Satakor, Gara Soge, Gara Yemoo, Gara Korbesa, Tulu Shimala and some part of Walal mountain are some of major hills found in the woreda. The woreda generally lies within altitudinal range of 1500 – 3303 metre above sea level. Its highest and lowest points lie in specific areas of Dati and Walal Mountain, respectively. The major rainy seasons in the woreda are spring (April - May), summer (Jun-August) and autumn (September - November). The annual rainfall of Efa Gudina sub watershed is 1500- 1800mm and annual temperature is ranges between 20 to 22.5°C.

Soil type and soil sampling**:** As shown in figure 3, there are six types soil found in the watershed. These are Arcisols, Alisols, Fluvisols, Luvisols, Nitosols and Vertisols. After preliminary studies of topographic maps (1:25000), using GPS, studying location was appointed. 45 soil samples were collected from different mapping unit located in the study area.

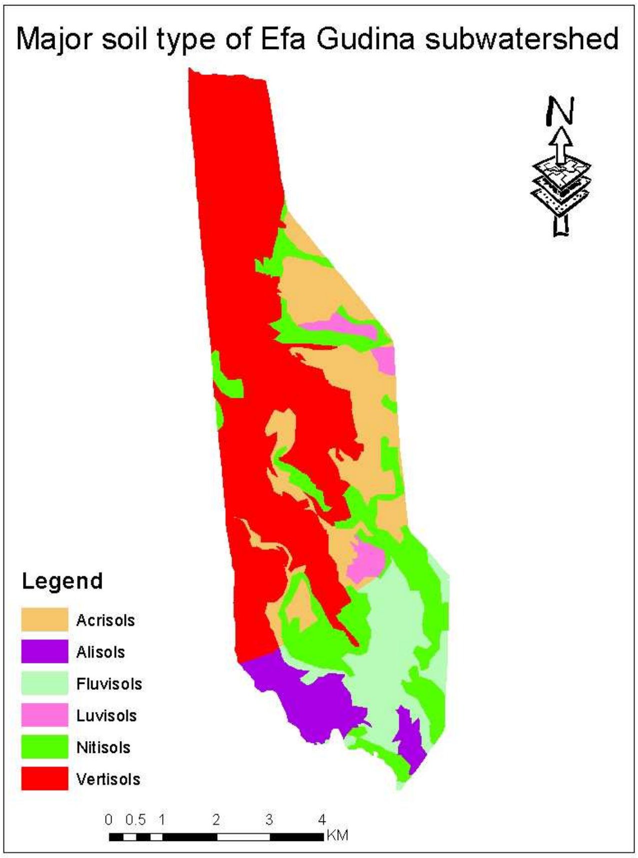

Figure 3. *Type of soil in Efa Gudina watershed.*

2.2. Laboratory Analysis

Physical and chemical properties of the sieved soil samples (<2mm) were determined after being air-dried. Organic Carbon (OC) was determined using Walkley-Blackmethod. Soil pH was determined in 1:2.5 (pH-H_2O) soil to water ratio, measured using a pH meter [23].

2.3. Land Evaluation Procedure

The suitability evaluation of the land was done using the conventional parametric method [9]. In the process of evaluation, a single evaluation is performed for each LUR of a LUT (Table 3). Then the diagnostic factors of each Land qualities are weighted using rating table as (table 2). After that the evaluation model is defined using the value of factor rating as suitability level *(S) =f (Soil condition (texture)* slope/ 100* depth/100*drainage/100*PH/100*OC/100)*. Each identified land mapping unit has been evaluated for its crop suitability for each selected land utilization type. Finally a resultant map is produce for both LTUs upon which the evaluation model is applied using GIS. The results of evaluation places the soil mapping units into one of the earlier defined physical suitability classes (S1, S2, S3, N1 and N2) based on how well the LURs of each SMU are satisfied by the prevailing LQs for each LUT. The final output of the evaluation procedures is physical suitability subclass (appendix A & B) with a subscript expressing type of limiting LURs and/or improvements to be considered. Expressions of suitability subclasses with more than one subscript imply that all those limit the suitability of recognized mapping unit for crop of the LUTs; the results of evaluation classification are shown in maps for each LUT.

2.4. Land Qualities and Land Characteristics

The descriptions made on the land use requirements of the selected LUTs and its corresponding variability among the land units guided the selection of appropriate land qualities to be used in suitability land evaluation of Efa Gudina watershed. Accordingly, climate characteristics (temperature and rainfall), and topography land quality (slope) and soil condition land qualities (texture, drainage, PH, OC and depth) were coded and used in the evaluation classification (tables 2 and 3). These correspond to the identified class determining factors (or called land use requirements) mentioned above. FAO [9] recommends considering land qualities that most affect the land use and those that have significant influence on the land management.

Table 2. *Crop Environment requirement for Suitability Rating of Maize (Zea mays).*

land quality	Symbol	climate charecteristics	Class, degree of limitation and rating scale				
			S1	S2	S3	N1	N2
climate	C	Annual Rainfall	750-500	500-400	400-300	-	<300
			750-1200	1200-1600	>1600	-	-
		Mean annual temperature	24-18	18-16	16-14	-	<14
			24-32	32-35	35-40	-	>40

Land qualiy	Symbol	Land characteristics	Class, degree of limitation and rating scale				
			S1	S2	S3	N1	N2
Topography	T	Slope (%)	0-2	2-4	4-6	-	>6
Soil condition	S	Daranaige (class)	Good, Moderate	Imperfect. Good	Poor and Aeric	Poor but, drainable	poor not, drainable
		Texture (class)	C<60s,Co,SiC,SiCL,C<60V, C>60S,L,SCL,Si,SiL,SC,CL	C>60V,SL,LfS,LS	Fs,S,LcS	-	cm,Sicm, cS
		Soil depth (cm)	>75	75-50	50-20	-	<20
		Organic Carbon (%)	>1.2	1.2-0.8	<0.8	-	-
		Soil reaction (PH)	6.6-5.8	5.8-5.5	5.5-5.2	<5.2	-
			6.6-7.8	7.8-8.2	8.2-8.5	-	>8.5

Table 3. *Crop Environment requirement for suitability rating of sorghum (sorghum bicolor).*

land quality	Symbol	climate characteristics	class, degree of limitation and rating scale				
			S1	S2	S3	N1	N2
climate	C	Annual Rainfall	600-400	400-300	300-150	-	<150
			600-900	900-1200	1200- 1400	-	>1400
		Mean annual temperature	25-21	21-18	18-15	-	<15
			25-26	26-32	>32	-	_

land quality	Symbol	Land characteristics	lass, degree of limitation and rating scale				
			S1	S2	S3	N1	N2
Topography	T	Slope (%)	0-2	2-4	4-6	-	>6
Soil condition	S	Drainage (class)	Good, Moderate	Imperfect. Good	Poor and Aeric	Poor but, drainable	poor not, drainable
		Texture (class)	C<60s,Co,SiC,SiCL, Si, SiL, SCC<60V,C>60S,L,SCL,	C>60V,SL,LS	Lfs, LS, S, fs, Lcs	-	cm,Sicm,cS
		Soil depth (cm)	>50	50-20	20-10	-	<10
		Organic Carbon (%)	>1.5	<0.8	_	-	-
		Soil reaction (PH)	6.5-5.5	5.5-5.3	5.3-5.2	<5.2	-
			6.5-8.2	8.2-8.3	8.3-8.5	_	>8.5

3. Results and Discussion

3.1. Climate Suitability Evaluation for Maize and Sorghum Production

The results of the climate considering, temperature suitability of Efa Gudina watershed show that is highly suitable (S1) for both Maize and Sorghum varieties production under rain fed conditions in all mapping unit (table 2 &3). But climate considering, rain fall suitability show that marginally suitable (S3) for Maize and permanently not suitable (N2) for sorghum in all mapping unit. The main limiting factor is the higher annual rainfall of the watershed relative to the optimum condition which tends to over. The requirement tables in table 2 indicate that highly suitable annual rain fall is range for Maize is between 750 and 1200 mm. However, the annual rain fall of the study area during the growing cycle is between 1500 and 1800mm falling in the range of >1600mm, which is marginally suitable (S3). And highly suitable annual rain fall is range for sorghum is between 600 and 900 mm (table 3). However, the annual rain fall of the watershed during the growing cycle is between 1500 and 1800 falling in the range of >1400, which is permanently not suitable (N2).

3.2. Topography Suitability Evaluation for Maize and Sorghum Production

The results of the ultimate landscape suitability evaluation showed that soil mapping units SMU 0, 1, 2. 3, 4, &19 is highly suitable and SMU5 to 13 is marginally suitable (S3) for both rain fed maize and sorghum production (table 2 and 3). On the other hand, soil mapping units SMU14, 15, 16, 17 & 18 and SMU20, 21, &22 permanently not suitable (N2) for both maize, and sorghum production due to problems related to sever erosion hazard. The requirement table in 2 &3 indicate that successful growth and production of maize and sorghum is in areas where the slope range is below 6%. But the watershed of the mapping units indicated that slope is >20%, which falls in the range of permanently unsuitable for the crops. Such hilly topography and convex moderately steep to steep nature of the slope is likely to cause severe soil erosion hazard.

3.3. Soil Suitability Evaluation for Maize and Sorghum Production

The results of soil suitability evaluation show that in all soil mapping unit soil condition (texture and depth) is highly suitable (S1) for rain fed maize production (Table 4). Soil condition drainage except SMU10, 11, 12 and 19 moderately (S2) suitable others SMU is highly suitable (S1) and OC only 5, 6, 7, 8 & 9 soil mapping units are marginally suitable the rest all SMUs are is highly suitable (S1) for rain fed maize production. Result of PH also indicates that SMU 0, 1, 2, 3 & 4 is highly suitable (S1), SMU 5, 6, 7, 8 & 9 is moderately suitable (S2) and other soil mapping units are currently not suitable (N1) for rain fed maize production. The requirement table in 4 & 5 indicates that maize can be grow successfully in soils with PH range 6.6-5.8 or 6.6-7.8. But soil mapping units of 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21 & 22 of the watershed falls below 4.7, which is currently not suitable (N1) for rain fed maize and sorghum production.

Similarly, depth in all SMUs and texture SMU 0, 1, 2, 3, 4, 5, 6, 7, 8 & 9 are highly suitable (S1) for rain fed sorghum production. Result of PH indicates that SMU 0 to 9 is highly suitable and other soil mapping units are currently not suitable (N1) for rain fed sorghum production. Soil condition drainage except SMUs 10, 11, 12 and 19 moderately (S2) suitable others SMU is highly suitable (S1) and OC only 5, 6, 7, 8 & 9 soil mapping units are moderately suitable the rest all SMUs are is highly suitable (S1) for rain fed sorghum production.

Table 4. *Maize Weight and Suitability Level.*

FID	Major_So_1	slope_rang	Slope_wt	Texture	Tex_wt	Soil depth (cm)	Soil depth Wt
0	Alisols	0-2	100	SCL	100	>150	95
1	Alisols	0-2	100	SCL	100	>150	95
2	Luvisols	0-2	100	SCL	100	>150	95
3	Luvisols	0-2	100	SCL	100	>150	95
4	Luvisols	0-2	100	SCL	100	>150	95
5	Acrisols	2-8	95	SCL	100	>150	95
6	Acrisols	2-8	95	SCL	100	>150	95
7	Acrisols	2-8	95	SCL	100	>150	95
8	Acrisols	2-8	95	SCL	100	>150	95
9	Acrisols	2-8	95	SCL	100	>150	95
10	Fluvisols	2-8	95	C L	95	>150	95
11	Fluvisols	2-8	95	Clay L	95	>150	95
12	Fluvisols	2-8	95	Clay L	95	>150	95
13	Nitisols	15-30	60	Clay L	95	>150	95
14	Nitisols	15-30	60	Clay L	95	>150	95
15	Nitisols	15-30	60	Clay L	95	>150	95
16	Nitisols	15-30	60	ClayL	95	>150	95
17	Nitisols	15-30	60	Clay L	95	>150	95
18	Nitisols	15-30	60	Clay L	95	>150	95
19	Vertisols	0-2	100	SCL	100	>150	95
20	Nitisols	8-15	85	Clay L	95	>150	95
21	Nitisols	8-15	85	Clay L	95	>150	95
22	Nitisols	8-15	85	Clay L	95	>150	95

Table 4. *Continued.*

FID	Drainage	Drai_Wt	PH	PH_Wt	OC_top	OC_Wt	index	Suit_Level
0	M/W	100	6.70	100.0	2.50	95.00	90	S1
1	M/W	100	6.70	100.0	2.50	95.00	90	S1
2	M/M	85	6.30	95.0	8.71	95.00	73	S1
3	M/M	85	6.30	95.0	8.71	95.00	73	S1
4	M/M	85	6.30	95.0	8.71	95.00	73	S1
5	W/W	100	5.60	60.0	0.20	40.00	22	S3
6	W/W	100	5.60	60.0	0.20	40.00	22	S3
7	W/W	100	5.60	60.0	0.20	40.00	22	S3
8	W/W	100	5.60	60.0	0.20	40.00	22	S3
9	W/W	100	5.60	60.0	0.20	40.00	22	S3
10	I/S	60	4.20	25.0	4.14	95.00	12	N1
11	I/S	60	4.20	25.0	4.14	95.00	12	N1
12	I/S	60	4.20	25.0	4.14	95.00	12	N1
13	W/W	100	4.70	25.0	4.20	95.00	13	N1
14	W/W	100	4.70	25.0	4.20	95.00	13	N1
15	W/W	100	4.70	25.0	4.20	95.00	13	N1
16	W/W	100	4.70	25.0	4.20	95.00	13	N1
17	W/W	100	4.70	25.0	4.20	95.00	13	N1
18	W/W	100	4.70	25.0	4.20	95.00	13	N1
19	I/S	60	4.70	25.0	10.40	100.00	14	N1
20	W/W	100	4.70	25.0	4.10	95.00	18	N1
21	W/W	100	4.70	25.0	4.10	95.00	18	N1
22	W/W	100	4.70	25.0	4.10	95.00	18	N1

Note: MW = moderately well drained, I/S = imperfect/water saturation, W/W = well drained, SCL = sandy clay loam, LC= clay loam.

Table 5. *Sorghum Weight and Suitability Level.*

FDI	Major_So_1	Slope	Slope_wt	Texture	Tex_wt	Depth_rang	Depth_Wt
0	Alisols	0-2	100	SCL	90	>150	95
1	Alisols	0-2	100	SCL	90	>150	95
2	Luvisols	0-2	100	SCL	90	>150	95

FDI	Major_So_1	Slope	Slope_wt	Texture	Tex_wt	Depth_rang	Depth_Wt
3	Luvisols	0-2	100	SCL	90	>150	95
4	Luvisols	0-2	100	SCL	90	>150	95
5	Acrisols	2-8	95	SCL	90	>150	95
6	Acrisols	2-8	95	SCL	90	>150	95
7	Acrisols	2-8	95	SCL	90	>150	95
8	Acrisols	2-8	95	SCL	90	>150	95
9	Acrisols	2-8	95	SCL	90	>150	95
10	Fluvisols	2-8	95	Clay L	70	>150	95
11	Fluvisols	2-8	95	Clay L	70	>150	95
12	Fluvisols	2-8	95	Clay L	70	>150	95
13	Nitisols	15-30	60	Clay L	70	>150	95
14	Nitisols	15-30	60	Clay L	70	>150	95
15	Nitisols	15-30	60	Clay L	70	>150	95
16	Nitisols	15-30	60	Clay L	70	>150	95
17	Nitisols	15-30	60	Clay L	70	>150	95
18	Nitisols	15-30	60	Clay L	70	>150	95
19	Vertisols	0-2	100	CL,SCL,L	90	>150	95
20	Nitisols	8-15	85	Clay L	70	>150	95
21	Nitisols	8-15	85	Clay L	70	>150	95
22	Nitisols	8-15	85	Clay L	70	>150	95

Table 5. *Continued.*

FDI	Drainage	Drai_Wt	PH	PH_Wt	OC_top	OC_Wt	index	Suit_Level
0	M/W	100	6.70	100.0	2.50	60	51.3	S1
1	M/W	100	6.70	100.0	2.50	60	5.13	S1
2	M/M	85	6.30	95.0	8.71	95	65.6	S1
3	M/M	85	6.30	95.0	8.71	95	65.6	S1
4	M/M	85	6.30	95.0	8.71	95	65.6	S1
5	W/W	100	5.60	85.0	0.20	60	41.4	S1
6	W/W	100	5.60	85.0	0.20	60	41.4	S1
7	W/W	100	5.60	85.0	0.20	60	41.4	S1
8	W/W	100	5.60	85.0	0.20	60	41.4	S1
9	W/W	100	5.60	85.0	0.20	60	41.4	S1
10	I/S	60	4.20	40.0	4.14	95	14.4	N1
11	I/S	60	4.20	40.0	4.14	95	14.4	N1
12	I/S	60	4.20	40.0	4.14	95	14.4	N1
13	W/W	100	4.70	40.0	4.20	95	15.2	N1
14	W/W	100	4.70	40.0	4.20	95	15.2	N1
15	W/W	100	4.70	40.0	4.20	95	15.2	N1
16	W/W	100	4.70	40.0	4.20	95	15.2	N1
17	W/W	100	4.70	40.0	4.20	95	15.2	N1
18	W/W	100	4.70	40.0	4.20	95	15.2	N1
19	I/S	60	4.70	40.0	10.40	100	20.52	S3
20	W/W	100	4.70	40.0	4.10	95	21.5	S3
21	W/W	100	4.70	40.0	4.10	95	21.5	S3
22	W/W	100	4.70	40.0	4.10	95	21.5	S3

3.4. Over All Suitability Evaluation

The overall suitability results are obtained by combining climatic and, soil and topography suitability classes for both LUTs. Since the study area fall under the same climatic condition the climatic characteristics are the same for all mapping units. Consequently, the climatic suitability for all the mapping units is set the same. As indicated in Tables 6 and map 2 to 3, 3.24 Km^2 (8.73%) of the watershed is highly suitable; 6.32 Km^2 (17.04%) is marginally suitable and 27.53 Km^2 (74.22%) currently not suitable for Maize production. Similarly, 9.56 Km^2 (25.77) of the watershed is highly suitable; 21.73 Km^2 (58.58%) is marginally Suitable and 5.80 Km^2 (15.63%) currently not suitable for sorghum production.

Table 6. *Crop suitability evaluation of land mapping units (LMUs).*

Suitability classes	Maize/ in MUs	Area (KM^2)	%	sorghum/ in MUs	Area (KM^2)	%
S1	SMU0 to4	3.24	8.73	SMU0 to 9	9.56	25.77
S3	SMU5 to 9	6.32	17.04	SMU19 to22	21.73	58.58
N1	SMU10 to 22	27.53	74.22	SMU10 to18	5.80	15.63

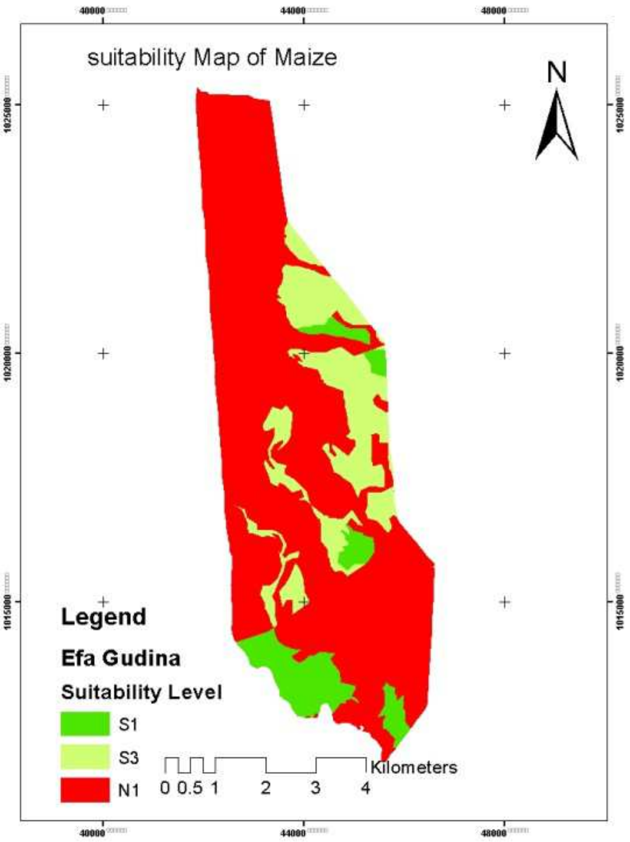

Figure 4. *Suitability of maize for sustainable rain-fed agriculture of Efa Gudina Watershed.*

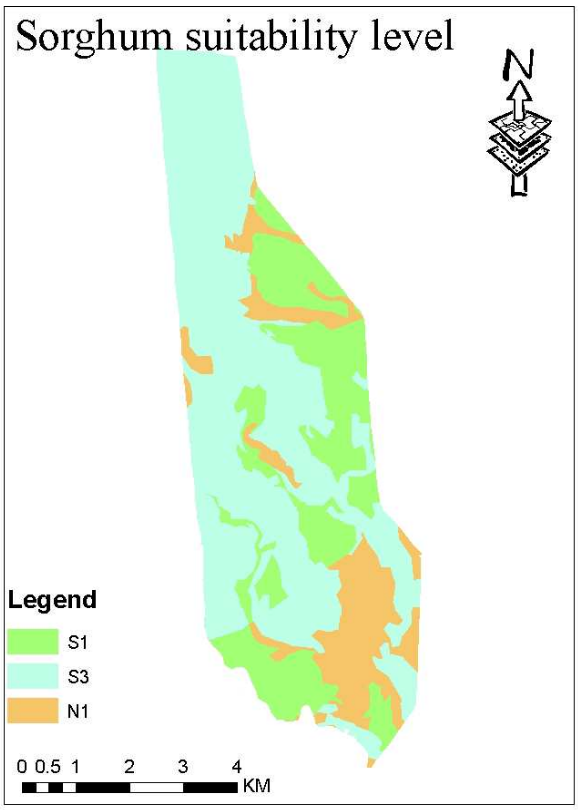

Figure 5. *Suitability of sorghum for sustainable rain-fed agriculture of Efa Gudina Watershed.*

Physical land suitability subclass results reveal that, in most SMUs of the Efa Gudina watershed, three major land qualities identified as maximum limiting factors in rain fed agriculture land suitability classification, these maximum limiting land qualities include climate (rain fall), topography land quality (slope) soil condition (PH) (Tables 4 & 5).

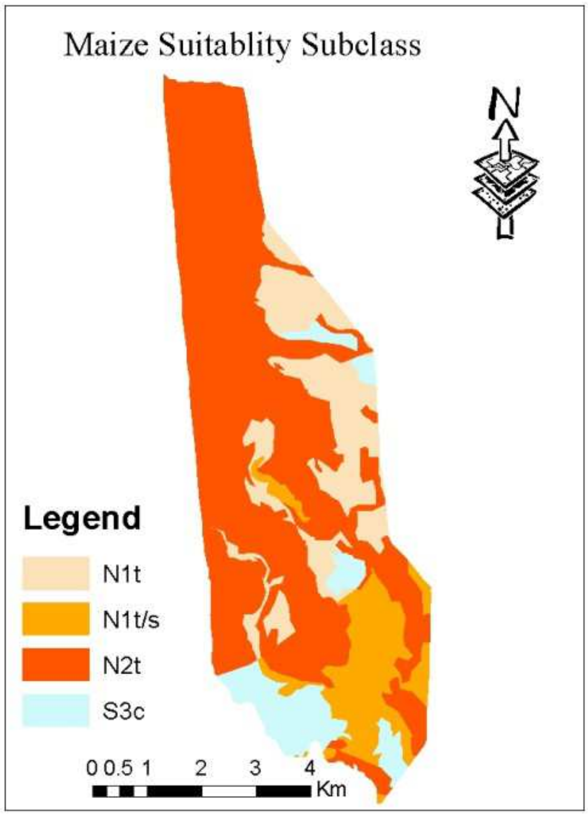

Figure 6. *Suitability subclass of maize for sustainable rain-fed agriculture of Efa Gudina Watershed.*

As indicated in Tables 7 and figure (5 and 6), 3.24 Km^2 (8.7%) of the watershed is classified as marginally suitable (S3c) as result of climate (high rainfall); 4.63 Km^2 (12.5%) is currently not suitable (N1t) due to steep slope factor additionally 4.32 Km^2 (11.6%) currently not suitable (N1t/s) due to due to combination factors of very steep slope which accelerate soil erosion and low PH i.e. high soil acidity. and 23.21 Km^2 (62.6%) permanently not suitable (N2t) for Maize production due to severe soil erosion factor. Similarly, 30.98 Km^2 (83.5%) of the watershed is permanently not suitable (N2c) due to high rainfall which accelerate again soil erosion and over land flow and 6.11 Km^2 (16.5%) permanently not suitable (N2c/t) for sorghum production as result of combination factors of high rain fall and very steep slope that means very sever soil erosion as well as difficult for cultivation.

The presence of limiting land qualities as discussed above implicates the need for improvements in overcoming the existing limitations in mapping units of the watershed. Considering the assumed level of technology and management options individual farmer (and his family) can manage land qualities such as, minor fertility, slight erosion and surface drainage through soil and water conservation and soil management. On the other hand, very steep slope affecting land quality sever erosion hazard, low pH values affecting land quality fertility and excess rain fall would be hard to achieve by individual farmer (and his family) and need major land improvement, soil and water conservation practices and mitigation measures for increased Maize and sorghum production in the watershed. As a result, all those limited by these land qualities would become potentially highly suitable for all land mapping units. Though, decision-making regarding selection of crop LUTs and mitigation measures to alleviate the identified crop production limitations could be based not only on the physical land evaluation but also on other aspects such as socio-economic evaluation which are also highly important [24].

Table 7. *Sorghum and Maize suitability subclass in the watershed.*

Maize			Sorghum		
Suitability subclasses	**Area (KM^2)**	**Area%**	**Suitability subclasses**	**Area (KM^2)**	**Area%**
S3c	3.24	8.7	N2c	30.98	83.5
N1t	4.63	12.5	N2c/t	6.11	16.5
N1t/s	4.32	11.6			
N2t	23.21	62.6			

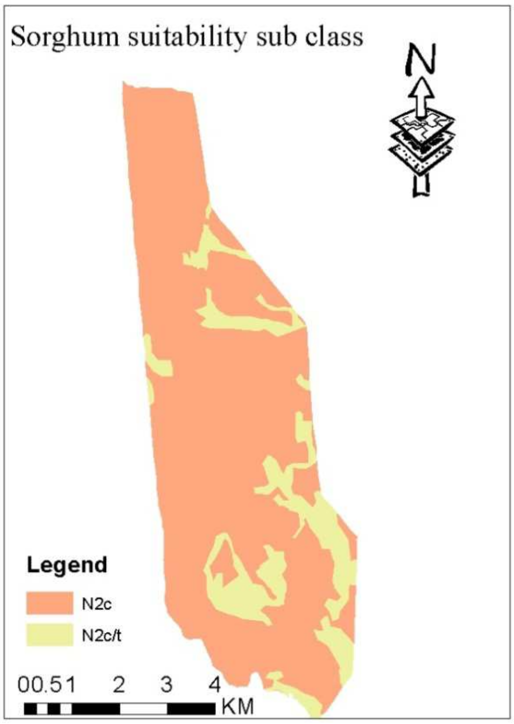

Figure 7. *Suitability subclass of sorghum for sustainable rain-fed agriculture of Efa Gudina Watershed.*

4. Conclusions

The physical land evaluation has delineated areas and produced potential land suitability map of the watershed that will allow growing the right crops at the right site for optimum yield and optimum return to investment for each crops. Based on the finding of this classification, the climate as evaluated through considering, temperature of Efa Gudina watershed is found suitable for cultivating certain crops including the present selected land utilization types. It is clear that the main limiting factors for crop suitability in the area are soil condition (low PH), slope and rain fall that need soil water conservation practices and mitigation measures.

Thus, the results of this study could be used to provide the baseline information needed for sustainable production of crops like maize and sorghum through mapping specific soil resource constraints in the study area. Secondly, this study can provide a framework for land use planning process by using GIS techniques, in order to enhance profitability land and sustainable crop production in the study area. It can also provide an important guidance for future land use planning and cost effective solutions in the sub watershed, where conditions are similar as in Efa Gudina. However, suitability for growing crop is not only limited by the selected physical constraints but also socioeconomic factors.

Appendix

Appendix A. Suitability Subclass of Maize

Table 8. *Land suitability Subclass of Maize.*

FID	Major_So_1	Temp	RF	slope_rang	Texture	Depth_rang	Drainage	PH	OC_top	suitable subclass	Maximum Limitation factor
0	Alisols	S1	S3	S1	S1	S1	S1	S1	S1	**S3c**	Climate
1	Alisols	S1	S3	S1	S1	S1	S1	S1	S1	**S3c**	Climate
2	Luvisols	S1	S3	S1	S1	S1	S1	S1	S1	**S3c**	Climate
3	Luvisols	S1	S3	S1	S1	S1	S1	S1	S1	**S3c**	Climate
4	Luvisols	S1	S3	S1	S1	S1	S1	S1	S1	**S3c**	Climate
5	Acrisols	S1	S3	S3	S1	S1	S1	S2	S3	N1t	Topography
6	Acrisols	S1	S3	S3	S1	S1	S1	S2	S3	N1t	Topography
7	Acrisols	S1	S3	S3	S1	S1	S1	S2	S3	N1t	Topography

FID	Major_So_1	Temp	RF	slope_rang	Texture	Depth_rang	Drainage	PH	OC_top	suitable subclass	Maximum Limitation factor
8	Acrisols	S1	S3	S3	S1	S1	S1	S2	S3	N1t	Topography
9	Acrisols	S1	S3	S3	S1	S1	S1	S2	S3	N1t	Topography
10	Fluvisols	S1	S3	S3	S1	S1	S2	N1	S1	N1t/s	Topography & soil condition
11	Fluvisols	S1	S3	S3	S1	S1	S2	N1	S1	N1t/s	Topography& soil condition
12	Fluvisols	S1	S3	S3	S1	S1	S2	N1	S1	N1t/s	Topography& soil condition
13	Nitisols	S1	S3	S3	S1	S1	S1	N1	S1	N1t/s	Topography& soil condition
14	Nitisols	S1	S3	N2	S1	S1	S1	N1	S1	N2t	Topography
15	Nitisols	S1	S3	N2	S1	S1	S1	N1	S1	N2t	Topography
16	Nitisols	S1	S3	N2	S1	S1	S1	N1	S1	N2t	Topography
17	Nitisols	S1	S3	N2	S1	S1	S1	N1	S1	N2t	Topography
18	Nitisols	S1	S3	N2	S1	S1	S1	N1	S1	N2t	Topography
19	Vertisols	S1	S3	S1	S1	S1	S1	N1	S1	N2t	soil condtion
20	Nitisols	S1	S3	N2	S1	S1	S2	N1	S1	N2t	Topography
21	Nitisols	S1	S3	N2	S1	S1	S1	N1	S1	N2t	Topography
22	Nitisols	S1	S3	N2	S1	S1	S1	N1	S1	N2t	Topography

FID	Major_So_1	Temp	RF	slope_rang	Texture	Depth_rang	Drainage	PH	OC_top	suitable subclass	Limitation
0	Alisols	S1	N2	S1	S1	S1	S1	S1	S1	N2c	Climate
1	Alisols	S1	N2	S1	S1	S1	S1	S1	S1	N2c	Climate
2	Luvisols	S1	N2	S1	S1	S1	S1	S1	S1	N2c	Climate
3	Luvisols	S1	N2	S1	S1	S1	S1	S1	S1	N2c	Climate
4	Luvisols	S1	N2	S1	S1	S1	S1	S1	S1	N2c	Climate
5	Acrisols	S1	N2	S3	S1	S1	S1	S1	S2	N2c	Climate
6	Acrisols	S1	N2	S3	S1	S1	S1	S1	S2	N2c	Climate
7	Acrisols	S1	N2	S3	S1	S1	S1	S1	S2	N2c	Climate
8	Acrisols	S1	N2	S3	S1	S1	S1	S1	S2	N2c	Climate
9	Acrisols	S1	N2	S3	S1	S1	S1	S1	S2	N2c	Climate
10	Fluvisols	S1	N2	S3	N1	S1	S2	N1	S1	N2c	Climate
11	Fluvisols	S1	N2	S3	N1	S1	S2	N1	S1	N2c	Climate
12	Fluvisols	S1	N2	S3	N1	S1	S2	N1	S1	N2c	Climate
13	Nitisols	S1	N2	S3	N1	S1	S1	N1	S1	N2c	Climate
14	Nitisols	S1	N2	N2	N1	S1	S1	N1	S1	N2c/t	climate &Topography
15	Nitisols	S1	N2	N2	N1	S1	S1	N1	S1	N2c/t	climate &Topography
16	Nitisols	S1	N2	N2	N1	S1	S1	N1	S1	N2c/t	climate &Topography
17	Nitisols	S1	N2	N2	N1	S1	S1	N1	S1	N2c/t	climate &Topography
18	Nitisols	S1	N2	N2	N1	S1	S1	N1	S1	N2c/t	climate &Topography
19	Vertisols	S1	N2	S1	N1	S1	S1	N1	S1	N2c	Climate
20	Nitisols	S1	N2	N2	N1	S1	S2	N1	S1	N2c/t	climate &Topography
21	Nitisols	S1	N2	N2	N1	S1	S1	N1	S1	N2c/t	climate &Topography
22	Nitisols	S1	N2	N2	N1	S1	S1	N1	S1	N2c/t	climate &Topography

Appendix B. Suitability Subclass of Sorghum

Maize																			
DRAINAGE			DEPTH		SLOPE		TEXTURE		SURFACE COURS		CaCo3		EC		PH		OC		
Weight			Weight	1	Weight	1	Weight	1	Weight	1	Weight	1	Weig	1			Weigh	1	
Code	fine	Coars	Value		Value		Code		Value		Value		Value				Value		
W	100	60	0	0	0	100	CL	95	N	100	0	100	0	100	0	25	0	40	60
R	85	85	20	40	4	95	SCL	100	V	95	6	95	2	95	5.2	40	40	40	85
S	60	100	50	60	8	85	SCL	100	F	85	15	85	4	85	5.5	60	0.4	40	85
L	40	40	75	85	16	60	LS	90	C	60	25	60	6	60	5.8	85	0.5	60	85
V	40	40	100	95	30	40	LS	100	M	40	35	40	8	40	6.2	95	0.8	85	95
NK	100	100	500	100	50	25	Si	95	A	25	200	0	12	25	6.6	100	12	95	100
					90	0	SC	100	D	0			100	0	7	95	10	100	100
							C	60							7.8	85			
							SC	90							8.2	60			
							SL	85							8.5	40			
							LC	85							9	0			
							S	50											

Sorghum																			
DRAINAGE			DEPTH		SLOPE		TEXTURE		SURFACE COURS		CaCo3		EC		PH		OC		
Weight			Weigl	1	Weight	1	Weight	1	Weight	1	Weight	1	Weig	1		1	Weigh	1	
Code	fine	Coars	Value		Value		Code		Value		Value		Value				Value		
W	100	60	0	0	0	100	CL	70	N	100	0	85	0	100	0	0	0	100	60
R	85	85	10	25	4	95	SCL	100	V	95	2	95	4	95	52	40	0.4	100	85
S	60	100	20	60	8	85	SCL	90	F	85	3	100	8	85	53	60	0.8	100	95
L	40	40	50	85	16	60	LS	90	C	60	20	95	12	60	55	85	10	100	100
V	40	40	90	95	30	40	LS	100	M	40	30	85	16	40	6	95			
NK	100	100	500	100	50	25	Si	100	A	25	45	60	20	25	6.5	100			
					95	0	SC	100	D	75	40		90	0	8.2	85			
							C	70		200	0				78	85			
							SC	100							8.3	60			
							SL	70							8.5	60			
							LC	50							9	0			
							S	50											

NB: the numbers are contin						
For example:				For Drainage		
value	means	Total Score		W=	Well Drained	Good
0	0-5	0-10	N2	R=	Rarely saturated	Moderate
6	6 to 15	11to20	N1	S=	saturated for short periods in most year	Imperfect
15	15-35	21-30	S3	L=	saturated for long periods every years	Poor &drainable
35	35-200	31-40	S2	V=	Very poorly Drai	poor &not drainable
200	>200	>40	S1	NK=	Not known	

Figure 8. *Rating Tables.*

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