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A Geographic Information System Based Physical Land Suitability Evaluation to Cereal and Pulse Crops in Guang Watershed, Highlands of Ethiopia

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Abstract
Land suitability mapping and analysis is a prerequisite to achieving optimum utilization of the available land resources. The main objective of this study conducted in 2014 wasto spatially evaluate land suitability for barley (*Hordeum vulgare* L.), sorghum (*Sorghum bicolor* L.), soyabean (*Glycine max L.)* and chickpea (*Cicer arietinum* L.) crops in the Guang watershed, Ethiopia based on FAO guidelines. Geographical Information System (GIS) techniques were used to develop land suitability map of the study watershed. Land characteristics (LC) and crop requirements were used as criteria for crop suitability analysis were soil (depth, texture and pH), slope and temperature. The crop suitability map of the study watershed was made in an area of about 2500 ha by matching between reclassified LC of the watershed with crop requirements using GIS model builder. The land use suitability analysis indicated that the watershed was highly (S1), moderately (S2), marginally (S3) and not suitable (N) for barley, sorghum, soyabean and chickpea were in an area of 756.75 ha (30.27%), 1441.8 ha (57.67%), 1540.5 ha (61.62%) and 703.75 ha (28.15%), respectively.
Keywords: physical land suitability evaluation; crop; GIS; Guang watershed; highlands Ethiopia

1. Introduction

Ethiopia has a considerable land resource for agriculture. About 73.6 million ha (66%) of the country's area is potentially suitable for agriculture (Fasil, 2002) and the Ethiopian agricultural sector has a proven potential to increase food supplies faster than the growth of the population (Davidson, 1992). Crop production plays a vital role in generating surplus capital to speed up the overall socio-economic conditions of the farmers. However, the country is unable to feed its people due to various bio-physical and socio-economic constraints and policy disincentives.

Agriculture is the basis for the economy of Ethiopia. It accounts for the employment of 90 percent of its population, over 50 percent of the country's gross domestic product (GDP) and over 90 percent of foreign exchange earnings (ECACC, 2002). Irrespective of this fact, the production system is dominated by small-scale subsistence farming system largely based on low-input and low-output rain fed agriculture. As the result, farm output lags behind the food requirement of the fast growing population. The high dependency on rain fed farming in the dry lands of Ethiopia and the erratic rainfall require alternative ways of improving agricultural production.

Soil erosion is becoming a major policy challenge in Ethiopia not only for increasing crop productivity but also for maintaining soil resource base for the future generation. It can pose a great concern to the environment because cultivated areas can act as a pathway for transporting nutrients, especially phosphorus attached to sediment particles, to river systems (Ouyang and Bartholic, 1997). Its effect is both on-site (decreased soil productivity) and off-site, with impacts on water quality that include increased sedimentation and probability of floods (El-Swaify, 1994; Zhou and Wu, 2008; Chiu *et al*., 2007). The net soil loss from cultivated fields due to erosion ranged from 20 to 100 tons ha^{-1} $year^{-1}$, with corresponding annual productivity loss of 0.1 to 2% of total production (Hurni, 1993). In other side, the potential of the land for crop production to sustainably satisfy the ever increasing food demand of the increasing population is declining as a result of severe soil degradation (Lal, 1994).

In order to produce products in an environmentally compassionate, socially acceptable and economically efficient and ensure optimum utilization of the available natural resource, land evaluation is required (Nisar Ahamed *et al*., 2000; Addeo *et al*., 2001). Land evaluation is also essential to assess the potential and constraints of a given land parcel for agricultural purposes (Rossiter, 1996) using satellite data and GIS which have strong capacity in data integration and analysis (Yamamoto *et al.,* 2003; Thavone *et al*., 1999; Quang Duc, 1999; Mongkolsawat *et al*., 1999; Mongkolsawat *et al*., 1997). To date, the FAO guidelines on the land evaluation system (FAO, 1976; 1983) are widely accepted for the evaluation. The guidelines involve the execution and interpretation of basic surveys of climate, soils, vegetation and other aspects of land in terms of the requirements of alternative forms of land use. Soil suitability evaluation, on the other hand, involves characterizing the soils in a given area for specific land use type. Certain groups of activities are common to all types of soil suitability evaluation and details of these activities which are carried out vary with circumstances. The suitability of a given piece of land is its natural ability to support a specific purpose and this may be major kind of land use, such as rain fed agriculture, livestock production, forestry (Ande, 2011).

Under the present situation, where land is a limiting factor, it is impractical to bring more area under cultivation to satisfy the ever growing food demand (Fischer *et al*., 2002). In other hand, the rapid population growth has caused increased demands for food while soil erosion and extensive deforestation continue (Fresco, 1992). Therefore, smart agriculture is required for sustainable use of soils that significantly determines the agricultural potential of an area. For this purpose, identifying the suitability of the land for different crops is one of the aspects in this system. Land suitability evaluation for various crops including barley (*Hordeum vulgare* L.), sorghum (*Sorghum bicolor* L.), soyabean (*Glycine max L.)* and Chickpea (*Cicer arietinum* L.) crops were not yet done in Guang watershed. Hence, the main objective of the study were to spatially evaluate the suitability of the selected crops using GIS tools; thereby identify the potential to expand the selected cereal and pulse crops cultivation in Guang watershed, Ethiopia.

2. Materials and Methods

2.1 Description of the Study Watershed

Guang watershed is located in North Gondar Zone of Amhara National Regional State at about 597 km northwestern of Addis Ababa. The watershed lies within 11035′59″ to 13049′12″ latitude and 35009′45″ to 37046′42″ longitude (figure 1). The total area of the watershed is about 2500 ha. Agro-ecologically, 51% and 49% of the watershed is found to be warm and hot zone, respectively. Rainfall in the watershed is ranging from 720 mm to 1253.2 mm. Temperature extends from $12.8^{0}{}_{C}$ to $30.15^{0}{}_{C}$ and altitude is ranging from 511 to 3043 m.a.s.l. The watershed exhibited a slope range of flat to very steep slopes with many tributaries as shown in figure (DSA and SCI, 2006).

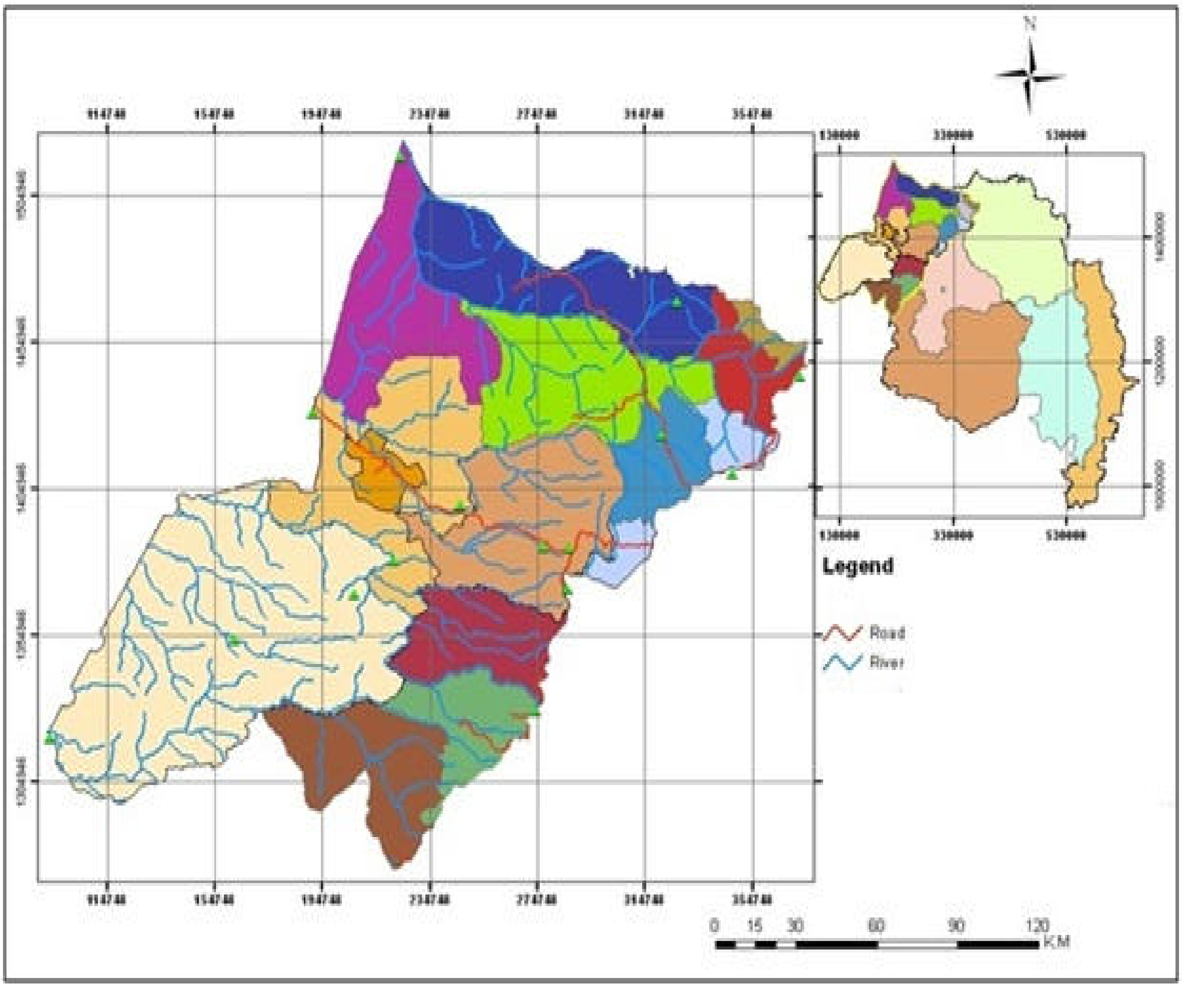

Figure 1: Location map of study watershed

2.2 Data Sources

The data sources consisted of different sets of primary, secondary and integrated database of spatial and non-spatial nature on different components of the study watershed. Soil and climate databases were obtained from the Amhara Regional soil and climate map developed by DSA and CSA (2006). The date sets were developed in excel computer program with the csv or dbf file format. Crop environmental requirements database was created in excel computer program with the csv or dbf file format as classifier or look up tables arranged from to values against the suitability classes. The 30 m spatial resolution DEM (digital elevation model) was used to generate slope by using "Spatial Analyst Tool Surface Slope" in ArcGIS environment.

2.3 Surface Soil Sampling and Analysis

Each major soil type was stratified based on soil color, texture and slope. The 30 m spatial resolution DEM (digital elevation model) was used to generate slope by using "Spatial Analyst Tool Surface Slope" in ArcGIS environment. Several auger observations were taken by Edelman auger at surface layer of different depths and bulked into 15 composite soil samples for crop suitability evaluation purposes (Figure 2). Surface soil samples from different soil types were collected and analyzed in the soil laboratory of Amhara Design and Supervision Works Enterprise (ADSWE).

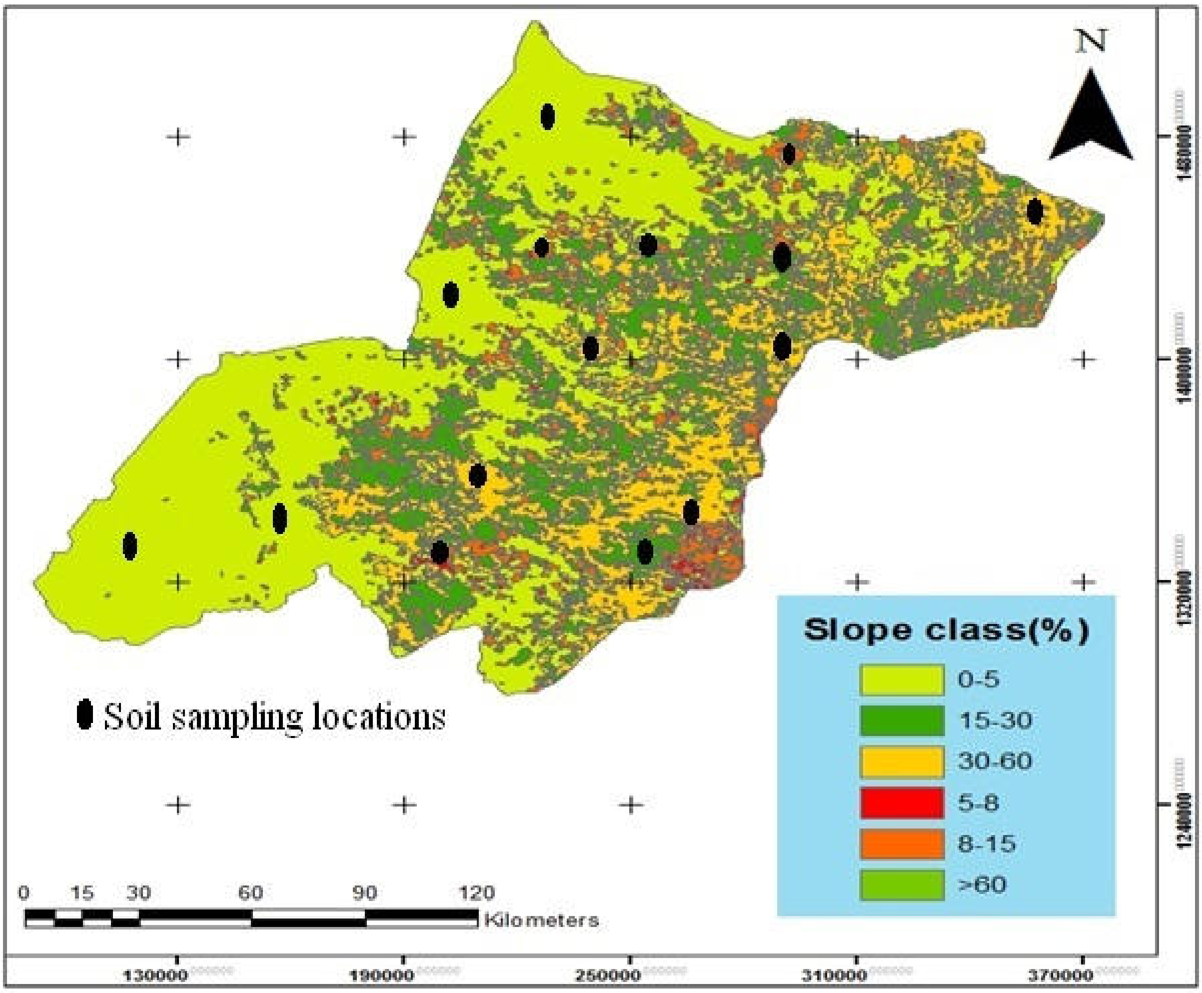

Figure 2: Soil sample locations along slope category

The soil samples collected from surface were air dried at room temperature and ground to pass through 2 mm sieve for the soil. Soil texture was determined by the hydrometer method as described in Bouyoucos (1962) where hydrogen peroxide was used to destroy OM and using sodium hexa-metaphosphate as dispersing agent. Then, hydrometer readings after 40 seconds and 2 hours were used to determine the silt plus clay and clay particles in suspension, respectively, whereas the percent of silt was calculated from the difference. Soil textural classes were determined following the textural triangle of USDA system as described by Rowell (1997). Soil pH was measured potentiometrically using a digital pH meter in the supernatant suspension of 1:2.5 (soil: water ratio).

Table 1: Soil laboratory results and characterization

Soil depth (cm)	Textural class	pH_{H2O}	TN (%)	AVP (ppm)	OC (%)
>150	Silty clay loam	4.64	0.1	2.69	221.12
>150	Silty clay loam	4.03	0.5	2.34	239.38
>150	Heavy clay	4.24	0.2	2.46	94.17
>150	Heavy clay	3.77	0.1	2.18	89.95
>150	Heavy clay	3.90	0.1	2.26	47.91
>150	Heavy clay	4.24	0.1	2.46	88.76
>150	Heavy clay	4.10	0.3	2.38	43.23
>150	Heavy clay	4.57	0.2	2.65	83.57
>150	Heavy clay	3.97	0	2.3	38.19
>150	Loam	4.44	0.1	2.57	100.94
>150	Loam	3.70	0.1	2.15	96.10
>150	Heavy clay	4.30	0.2	2.5	74.14
>150	Heavy clay	3.77	0.1	2.18	74.43
>150	Heavy clay	4.64	0.1	2.69	30.56
>150	Clay	3.83	0.3	2.22	97.37

Table 2: Suitability of physical suitability, limitations and proportional area of maize and wheat

No.	Suitability Subclass	Maize		Wheat	
		Area (ha)	Cover (%)	Area (ha)	Cover (%)
1	N	1459.32	36.483	1464.12	36.603
2	S1	232.08	5.802	321.68	8.042
3	S2e	0.12	0.003	1.24	0.031
4	S2k	109.76	2.744	666.76	16.669
5	S2m	608.4	15.21	409.2	10.23
6	S2n	193.16	4.829	82.36	2.059
7	S2r	133.44	3.336	516.56	12.914
8	S2t	169.96	4.249	11.68	0.292
9	S2z	9.08	0.227	4.32	0.108
Subtotal for moderately suitable land		1223.92	30.598	1692.12	42.303
10	S3k	156.8	3.92	1.24	0.031
11	S3m	119.84	2.996	215.32	5.383
12	S3n	698.24	17.456	268.52	6.713
13	S3r	2.8	0.07	2.32	0.058
14	S3t	1.24	0.031	0.48	0.012
15	S3z	105.84	2.646	34.24	0.856
Subtotal for marginally suitable land		1084.76	27.119	522.12	13.053

Table 3: Suitability, limitations and proportional area of chickpea and soybean

No.	Class	Limitations	Chickpea		Soybean	
			Area (ha)	Cover (%)	Area (ha)	Cover (%)
1	N	LGP	244	6.1	80	2
2	N	Slope	1456	36.4	684	17.1
3	N	Soil depth	96	2.4	408	10.2
4	N	slope	112	2.8	380	9.5
5	N	SOM	44	1.1	92	2.3
6	N	Soil texture	128	3.2	84	2.1
7	N	pH	300	7.5	152	3.8
Subtotal for unsuitable land (N)			2380	59.5	1880	47
8	S2	LGP	288	7.2	228	5.7
9	S2	Slope	348	8.7	396	9.9
10	S2	Soil depth	52	1.3	100	2.5
11	S2	slope	180	4.5	108	2.7
12	S2	SOM	84	2.1	140	3.5
13	S2	pH	44	1.1	96	2.4
Subtotal for moderately suitable land (S2)			996	24.9	1068	26.7
14	S3	LGP	168	4.2	364	9.1
15	S3	Slope	84	2.1	260	6.5
16	S3	Soil depth	96	2.4	152	3.8
17	S3	slope	116	2.9	88	2.2
18	S3	SOM	52	1.3	84	2.1
19	S3	Soil texture	56	1.4	104	2.6
20	S3	pH	52	1.3	1052	26.3
Subtotal for marginally suitable land (S3)			624	15.6		

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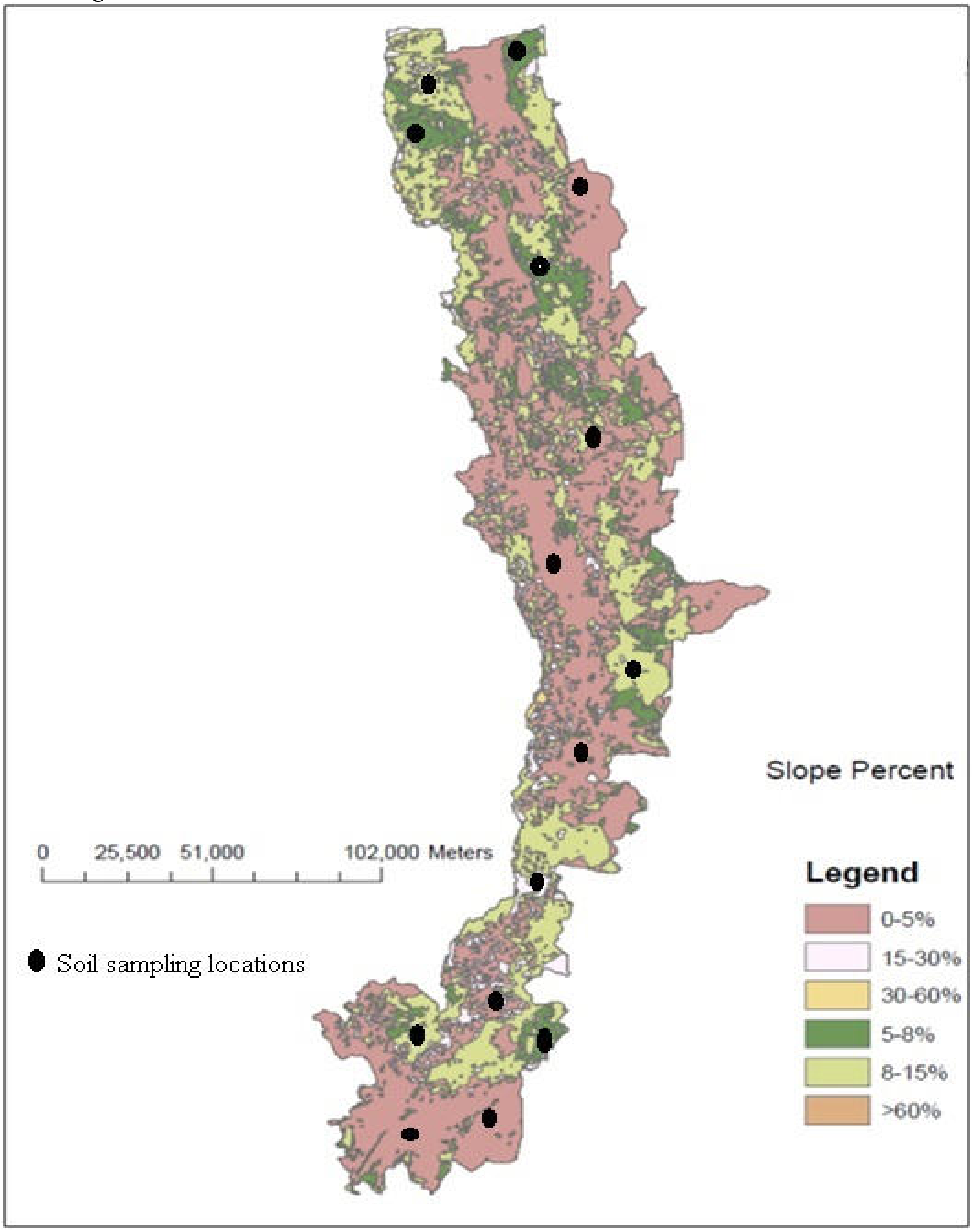

Figure 3: Soil sample locations along slope category

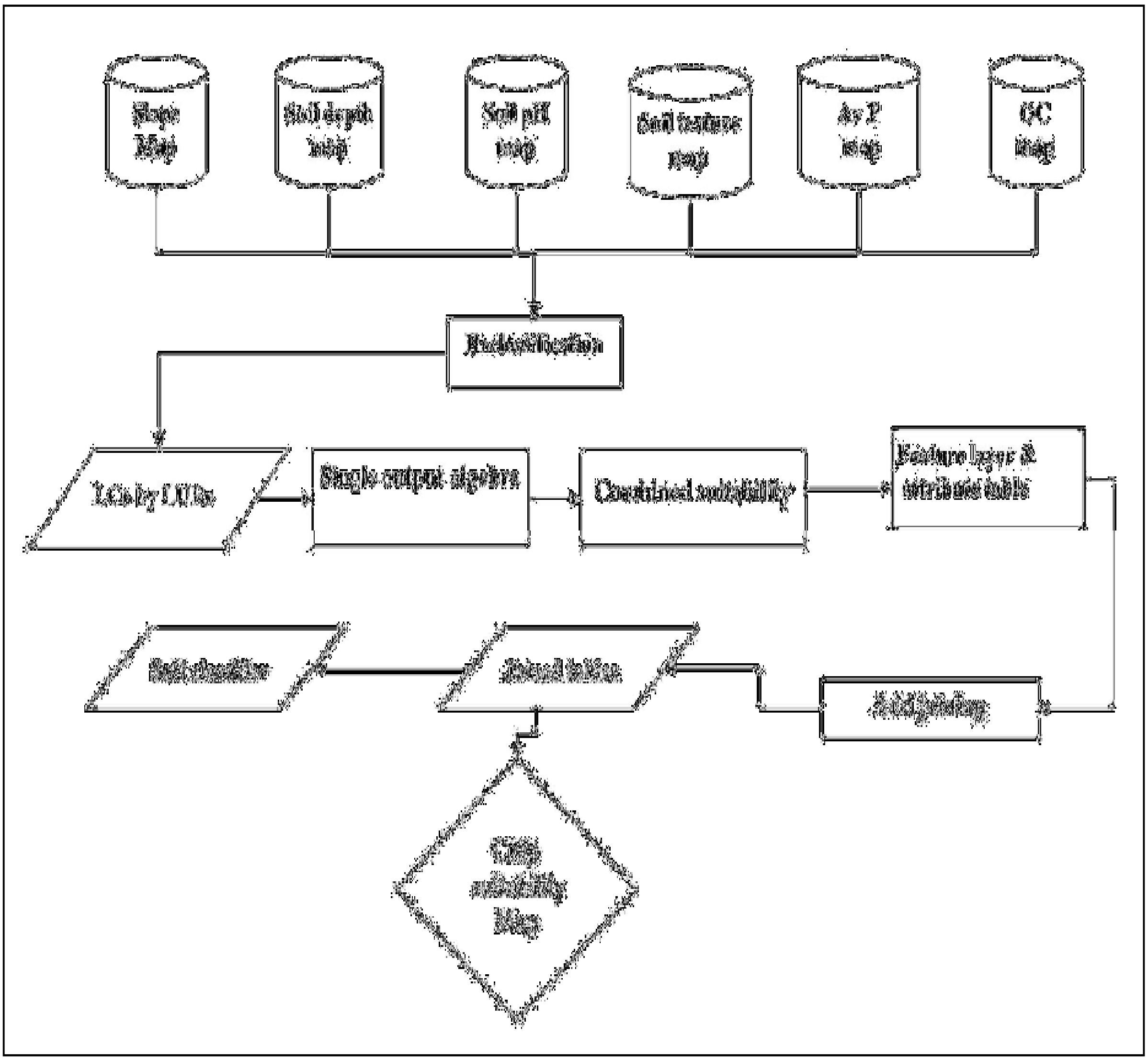

Figure 4: Model used in the study

2.3 Land Suitability Evaluation and Classification

The crop land utilization types for barley (*Hordeum vulgare* L.), sorghum (*Sorghum bicolor* L.), soyabean (*Glycine max L.)* and Chickpea (*Cicer arietinum* L.)) were selected through discussion with the key informant farmers and development agents. When crop selection was carried out, area coverage, importance of the crops in the livelihood of the concerned community, suitability of soils and agro-climatic conditions of the study watershed were evaluated. The crop land use requirements (LURs) were also selected based on agronomic knowledge of local experts and reviews of existing literatures such as FAO framework for land evaluation (FAO, 1998). The crop LURs in terms of the land qualities to be used in the evaluation process were treated as a thematic layer in the GIS database. Digital data of selected land characteristics (LCs) of the watershed and classifier look up tables for crop LURs were properly encoded to the Microsoft Office Excel sheet as database file to be used in ArcGIS for spatial analysis. The LCs were reclassified based on crop LURs.

The evaluation criteria used to address the suitability of the selected crop LUTs in the study watershed were soil (texture, pH and available P), slope, and temperature factors and were rated based on FAO land evaluation system using (FAO, 1976; 1983) guidelines. Individual land suitability classifications at present condition was then made in an area of about 2500 ha by matching between reclassified LCs of the watershed with crop LURs using GIS model builder (Figure 3). The model builder uses maximum limitation method so that the most limiting climatic or soil parameter dictates the final level of suitability (Sys *et al*., 1991; Van Diepen *et al*., 1999). Ground truth data collected from selected GPS points were used for checking and validation of results. All the maps were geo-referenced using the Universal Transverse Mercator (UTM) coordinate system.

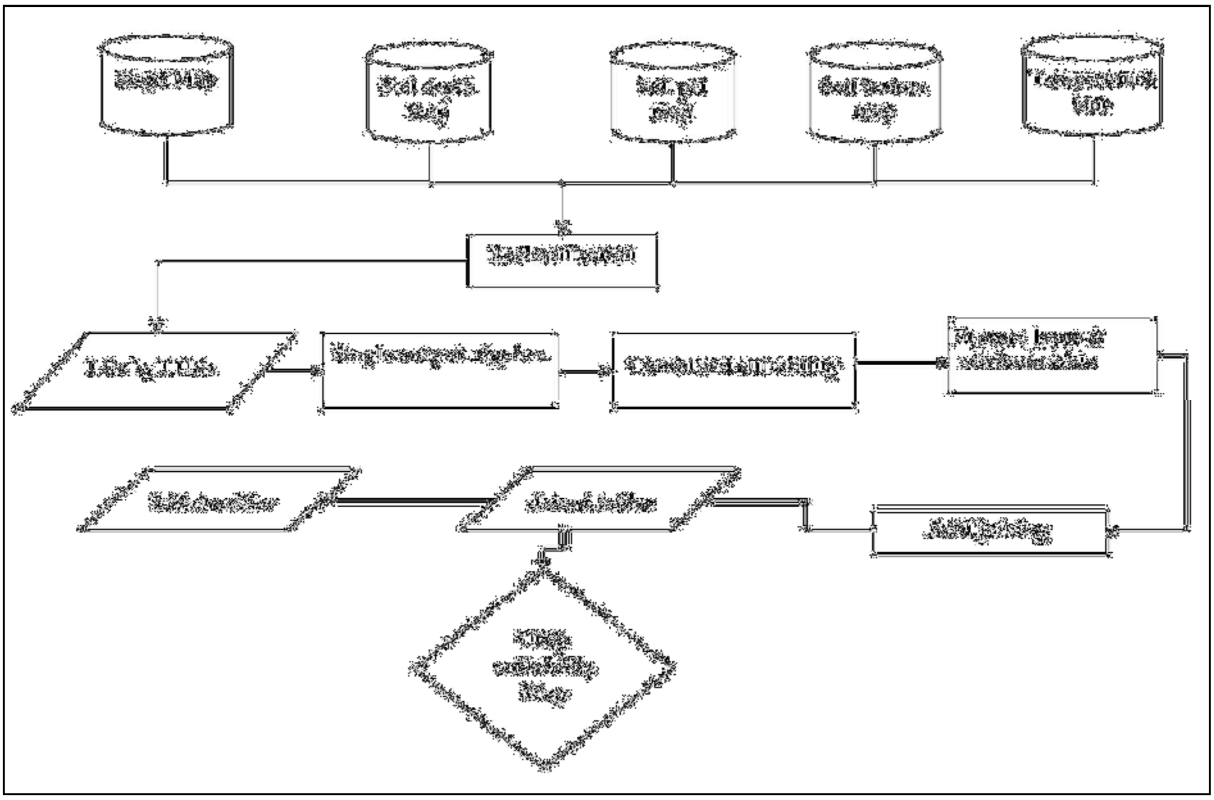

Figure 5: Overall methodology followed and outputs produced in ArcGIS environment

3. Results and Discussion

The factors influencing barley (*Hordeum vulgare* L.), sorghum (*Sorghum bicolor* L.), soyabean (*Glycine max L.)* and Chickpea (*Cicer arietinum* L.) yields and their suitability are slope, temperature, soil depth, texture, pH, available phosphorus, etc (FAO, 1998). Considering these land qualities, the watershed has been classified into four suitability classes as highly suitable, moderately suitable, marginally suitable and not suitable for the aforementioned crops. As indicated in Tables 2-3 and figures 4-7, 756.75 ha (30.27%) of the watershed were highly suitable; (1540.5 ha (61.62%) were moderately suitable for soyabean production. Similary, 1441.8 ha 57.67(%) of the watershed was marginally suitable for barley cultivation and (703.75ha (28.15%) of the same not suitable for chickpea production. It was clear that the same parcel of land was suitable for all crops bringing competing nature of crop LUTs. The current limiting factors for all crop suitability in the study area were soil texture (k), soil depth (r) and temperature (t) limitations that need mitigation measures. For increased barley, sorghum, chick pea and soyabean production in the watershed, corrective measures on the identified limitations should be taken. However, decision-making regarding selection of crop LUTs and mitigation measures to alleviate the identified crop production limitations could be based not only on the information provided by this study but also on other aspects such as socio-economic evaluation which are also highly important (Ceballos-Silva and Lopez-Blanco, 2002).

Land suitability for barley

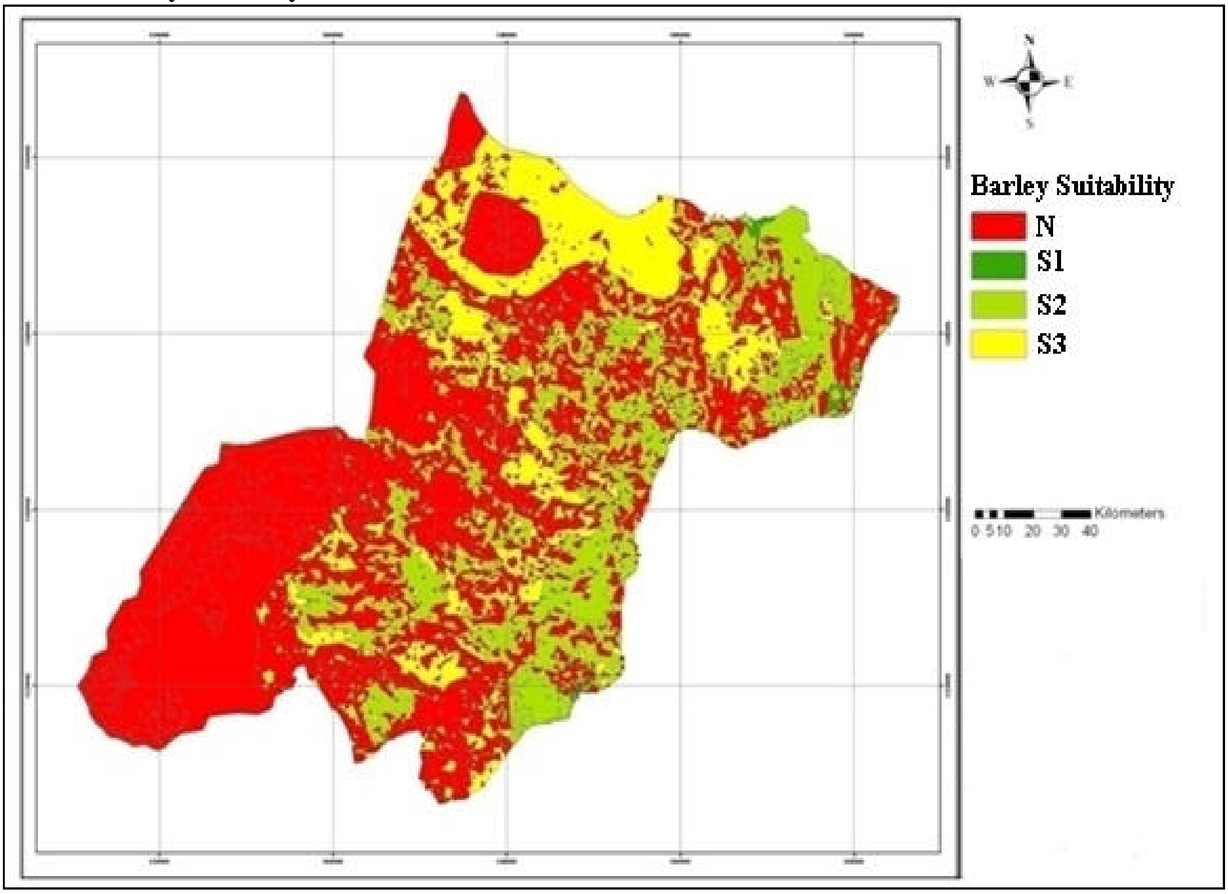

Figure 6: Barley suitability map

Table 4: Barley and Sorghum suitability in the watershed

Barley			Sorghum		
Suitability subclasses	Area (ha)	Area (%)	Suitability subclasses	Area (ha)	Area (%)
S1	11.75	0.47	S1	190.75	7.63
S2k	365.75	14.63	S2r	161.5	6.46
S2r	6.25	0.25	S2k	8	0.32
S2t	203.25	8.13	S2t	1035.8	41.43
Sub total	372	14.88		1396	55.84
S3k	11	0.44	S3r	0.75	0.03
S3r	5.75	0.23	S3k	0.5	0.02
S3t	454.25	18.17	S3pH	212.64	7.39
Sub total	674.25	26.97		186	7.44
Nk	592	23.68	Nr	1	0.04
Np	490	19.6	Nk	28.75	1.15
Nt	359.75	14.39	NpH	888.25	35.53
Sub total	1441.8	57.67		918	36.72

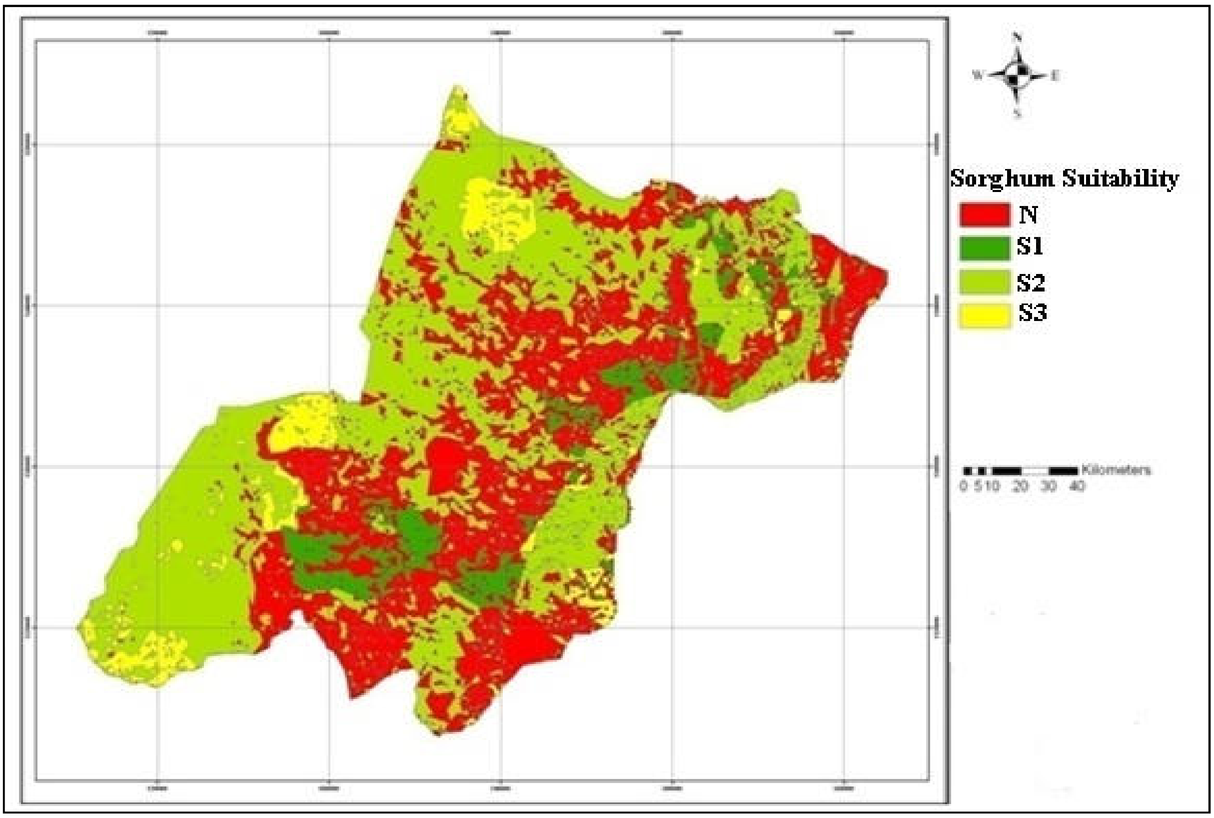

Figure 7: Sorghum suitability map

Land suitability for chick pea

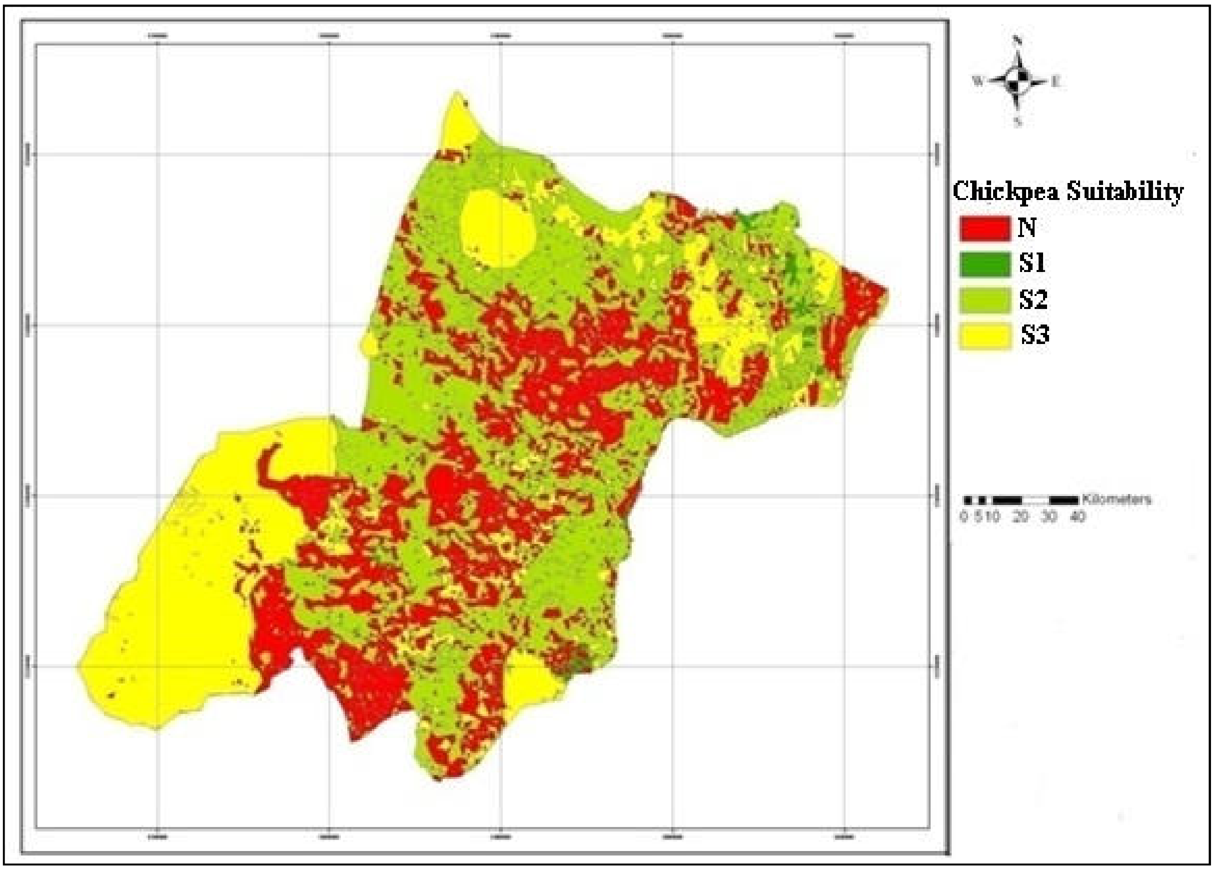

Figure 8: Chickpea suitability map

Table 5: Chickpea and Soyabean suitability in the watershed

Chickpea			Soyabean		
Suitability subclasses	Area (ha)	Area (%)	Suitability subclasses	Area (ha)	Area (%)
S1	21.25	0.85	S1	756.75	30.27
S2k	391.75	15.67	S2k	248.75	9.95
S2r	258.5	10.34	S2r	127	5.08
S2t	412.25	16.49	S2t	408	16.32
Sub total	1062.5	42.5		1540.5	61.62
S3r	176.75	7.07	S3k	5.5	0.22
S3t	465	18.6	S3r	154	6.16
S3k	62	2.48	S3t	45.25	1.81
Sub total	703.75	28.15		204.75	8.19
Nspl	31	1.24	Nk	180	7.2
Np	510.75	20.43	Nr	396	15.84
Nt	170.75	6.83	Nt	178.75	7.15
Sub total	712.5	28.5	Sub total	754.75	30.19

Land suitability for soybean

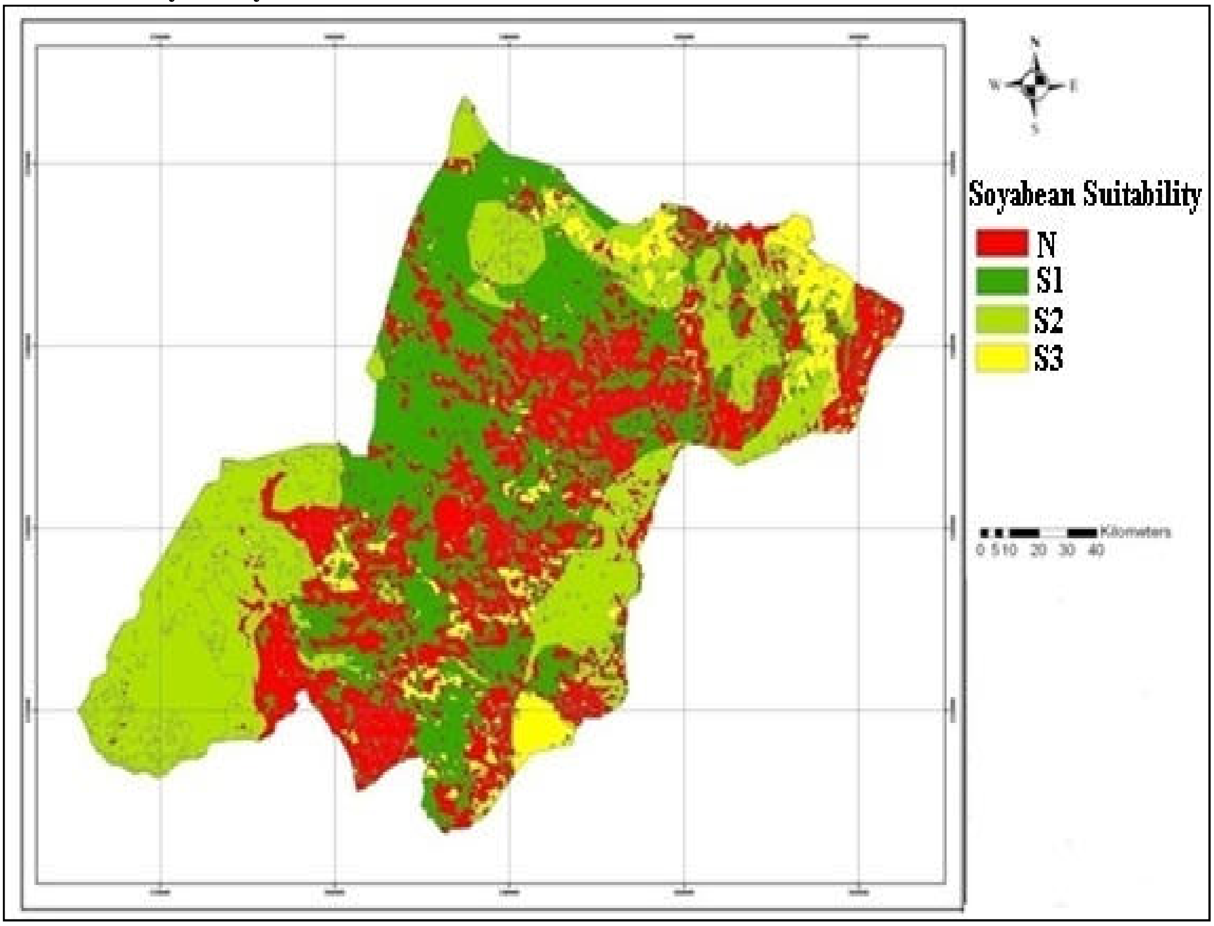

Figure 9: Soyabean suitability map

4. CONCLUSIONS

This study provides information about the areas suitable for crops individual crop types. The spatial information provided in GIS offers the decision maker with reasonable suitability maps. The GIS-based land evaluation approach can provide thematic layers that enable the formulation of dynamic scenarios for integrating land information. The study revealed that GIS technique was found to be t essential tool for the crop land suitability evaluation of the Guang watershed.

The study has delineated areas and produced potential land suitability map of the watershed that will allow growing the right cereal and pulse crops at the right site for optimum yield and optimum return to investment for each crops. Based on the finding of this study, it was clear that the main limiting factor for crop suitability in the area were soil pH, texture, soil depth, slope and temperature limitations that need mitigation measures. However, suitability for growing crop is not only limited by the selected pedo-edaphic and agro-climatic constraints but also socioeconomic factors which should be encorporated for further study. The variation in results of this study was apparently due to the values of each land qualities of the watershed. To validate the variations observed in the spatial analysis depending on the accuracy of input variables obtained from database, other empirical research need to be carried out.

5. References

Addeo G, Guastadisegni G, Pisante M (2001) Land and water quality for sustainable and precision farming. I World Congress on Conservation Agriculture, Madrid

Ande, O. T (2011). Soil Suitability Evaluation and Management for Cassava Production in the Derived Savanna Area of Southwestern Nigeria. International Journal of Soil Science, 6, pp. 142-149.

Ceballos-Silva, A, and J. Lopez-Blanco, 2002. Evaluating biophysical variables to identify suitable areas for oat in Central Mexico: a multi-criteria and GIS approach. *Agriculture Ecosystem and Environment Journal*, 95: 371-377.

Chiu Y. J., Borghuis A. M., Lee H. Y., Change K. T., and Chao J. H. 2007, Estimation of soil erosion in a reservoir watershed using 137cs fallout radionuclide. International Journal of Sediment Research, 22, pp. 304–317.

Davidson, D. A (1992). *The Evaluation of Land Resources*. Stirling University press, USA, NewYork.

Development Studies Associates (DSA) & Shawel Consult International (SCI) (2006). *Potential Survey, Identification of Opportunities and Preparations of Projects Profiles and Feasibility Studies*. Addis Ababa, Ethiopia.

Duc, H.Q., 1999. Geographic Information System (GIS) as a Tool for Land Evaluation and Land Use Planning. Paper presented at the Application of Resource Information Technologies (GIS/GPS/RS) in Forest Land and Resources Management Workshop, Hanoi, Vietnam.

Ethiopian Central Agricultural Census Commission (ECACC) (2002). A Report on Preliminary Results of Area, Production and Yield of Temporary Crops (Meher Season Private Peasant Holding), Part II, on Ethiopian Agricultural Sample Enumeration, Addis Ababa, Ethiopia.

El-Swaify S. A. 1994, State-of-the-art for assessing soil and water conservation needs and technologies, in: Napier, T. L., Camboni S. M., El-Swaify, S. A., (Eds.), Adopting conservation on the farm. Ankeny, IA: Soil and Water Conservation Society of America, pp. 13-27.

FAO (1976). *Framework for Land Evaluation* (pp. 17-21). FAO Soil Bulletin No.32, *FAO,* Rome.

FAO (1983). *Guidelines: Land Evaluation for Rainfed Agriculture. FAO Soils Bulletin no. 52*, FAO, Rome.

FAO (1998). *Guidelines on Land Evaluation for Rainfed Agriculture*. Soils Bulletin No.52, FAO, Rome, Italy.

Fasil, K (2002). *Analysis of Yield Gap for Wheat Cultivation in the Highlands of North Ethiopia.* Ph.D. Thesis, Gent University, Belgium.

Fischer, G., Velthuizen H.V., Shah M. & Nachtergaele F (2002). *Global Agro-ecological Assessment for Agriculture in the 21st Century: Methodology and Results.* International Institute for Applied Laxenburg in Australia.

Fresco, L.O., Huizing, H.G.J., Van Keulen, H., Luning, H.A. and Schipper, R.A. (1992), Land evaluation and farming systems analysis for land-use planning. FAO guidelines: Working document, ITC and Wageningen Agricultural University, Wageingen, the Netherlands.

Hurni, H (1993). Land degradation, famine and land resource scenarios in Ethiopia. In: Pimentel D (ed) World soil erosion and conservation. Cambridge University Press, Cambridge, pp. 27-62.

Lal, R (1994). Sustainable land use systems and soil resilience. In D. J. Greenland & I. Szabolcs (Eds.), *Soil Resilience and Sustainable Land Use*, pp. 41-67. UK: CAB International.

Mongkolsawat, C., Thirangoon, P., & Kuptawutinan, P., 1997. A Physical Evaluation of Land Suitability For Rice: A Methodological Study using GIS. Proceedings of the 18th Asian Conference on Remote Sensing. Malaysia.

Mongkolsawat, C., Thirangoon, P., & Kuptawutiana, P., 1999. Land Evaluation for Combining Economic Crops using GIS and Remotely Sensed Data. Proceedings of the 2nd Asia Pacific Conference on Sustainable Agriculture, Pitsanulok, October 18-20.

Nisar Ahamed TR, Gopal Rao K, Murthy JSR (2000) GIS-based fuzzy membership model for crop-land suitability analysis. Agr Syst 63(2):75-95.

Ouyang, D., Bartholic, J., 1997. Predicting sediment delivery ratio in Saginaw Bay watershed. Proceedings of the 22nd National Association of Environmental Professionals Conference. May 19-23, 1997, Orlando, FL, pp. 659-671.

Rossiter, G D, (1996). A theoretical frame work for land evaluation. *Goederma*, 72, 165-190.

Sys, I., Van Ranst E. & Debaveye J (1991). Part II Methods in Land Evaluation. *Agriculture Publication No.7, General Administration for Development Cooperation,* pp. 70-76. Brussels, Belgium.

Thavone, I., 1999. The Use of Geographic Information Systems for Soil Survey and Land Evaluation. Paper presented at the Application of Resource Information Technologies (GIS/GPS/RS) in Forest Land and Resources Management Workshop, Hanoi, Vietnam.

Van, Diepen, C. A., Van Keulen H., Wolf J. & Berkhout J. A. A (1999). Land Evaluation: From Intuition to Quantification. In B. A. Stewart (Ed.), *Advances in Soil Science,* pp. 139-204. New York: Springer.

Yamamoto, Y., & Sukchan, S., 2003. Land Suitability Analysis Concerning Water Resource and Soil Property. JIRCAS Working Report No.30. (pp. 25-31). Thailand.

Zhou P, Luukkanen O, Tokola T, Nieminen J (2008) Effect of vegetation cover on soil erosion in a mountainous watershed.Catena 75:319-325.