Land Suitability Evaluation for surface and sprinkler irrigation Using Geographical Information System (GIS) in Guang Watershed, Highlands of Ethiopia

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Abstract
The main objective of this study was to spatially evaluate land suitability for surface and sprinkler irrigation in the Guang watershed, Ethiopia based on FAO guidelines. Geographical Information System (GIS) techniques were used to develop land suitability map. The 30 m spatial resolution Digital Elevation Model was used to generate slope by using "Spatial Analyst Tool Surface Slope" in ArcGIS environment. Land characteristics (LCs) used as criteria for irrigation requirements were soil depth, soil texture, electric conductivity, pH, drainage and slope factors. The irrigation suitability map was made by matching between reclassified LCs with irrigation land use requirements (LURs) using GIS model builder. Surface soil samples from different soil types were collected and analyzed in the soil laboratory of Amhara Design and Supervision Works Enterprise (ADSWE). The crop suitability evaluation was made by matching between reclassified LCs of the watershed with crop LURs using GIS model builder. The results showed that 990.25 ha (39.61%) of the Guang watershed were highly suitable (S1) for surface irrigation method. However, 2370 ha (94.8%) of the region was unsuitable (N) for sprinkler irrigation method due to soil salinity, drainage and pH. This showed that the surface irrigation method was more efficient than the sprinkler irrigation method to intensively and extensively use the land. The resultant map can assist decision makers in ensuring that lands are used according to their suitability.
Keywords: land suitability evaluation, irrigation methods, GIS, Guang watershed

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% of its population, over 50% of the country's gross domestic product (GDP) and over 90% of foreign exchange earnings (ECACC, 2002). Irrespective of this fact, 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 and Chiu *et al*., 2007). The net soil loss from cultivated fields due to erosion ranged from 20 to 100 t/ha per year, 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 and Addeo *et al*., 2001). Land evaluation is also essential to assess the potential and constraints of a given land parcel for agricultural purposes (Rossiter, G. D., 1996) using satellite data and GIS which have strong capacity in data integration and analysis (Yamamoto *et al.,* 2003, Thavone *et al*., 1999, Mongkolsawat *et al*., 1999 and 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, successful agriculture is required for sustainable use of soils that significantly determine the agricultural potential of an area. Land suitability evaluation for surface and sprinkler irrigation methods were not yet done in Guang watershed. This calls for a need to conduct detailed studies at watershed level for use in crop suitability analysis. Hence, the main objective of the study were to spatially evaluate the suitability of the irrigation methods using GIS tools thereby identify their potentials in Guang watershed, Ethiopia.

Agriculture is the basis for the economy of Ethiopia. It accounts for the employment of 90% of its population, over 50% of the country's gross domestic product (GDP) and over 90% of foreign exchange earnings (ECACC, 2002). It has also a proven potential to increase food supplies faster than the growth of the population (Davidson, 1992). However, the country is unable to feed its people.

Land suitability is the fitness of a given type of land for a defined use. It is strongly related to erosion resistance, water availability and flood hazards which are derived from slope angle and length, rainfall and soil texture which are measurable or estimable in the land suitability studies, and then use them for determining the land suitability for irrigation purposes (FAO, 1976 and Sys *et al*., 1991). Land-use suitability mapping and analysis is one of the most useful applications of Geographical Information System (GIS) for spatial planning and management (Collins *et al*., 2001; Malczewski, 2004). It is also a prerequisite for land-use planning and is carried out to estimate the suitability of land for a specific us (Sys, 1985; Van Ranst, 1996 and FAO, 1976). It provides information on the constraints and opportunities for the use of the land and therefore guides decisions on optimal utilization of land resources (FAO, 1983).

GIS-based land suitability analysis is essential to assess the potential and constraints of a given land parcel for agricultural purposes (Rossiter, G. D., 1996). To date, the FAO guidelines on the land evaluation system (FAO, 1976, 1983) are widely accepted for the evaluation. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses (FAO, 1976). Irrigation land suitability analysis is given to the physical and chemical properties of soil and topographic (slope) factors in relation to methods of irrigation considered (FAO, 2007; Haile Gebrie, 2007 and Meron, 2007). The suitability of these factors for surface irrigation method and for the given land utilization types can be expressed corresponding to the following suitability classes (FAO, 1976, 1983, 1985): S1 (highly suitable); S2 (moderately suitable); S3 (marginally suitable) and N (unsuitable).

Ethiopia depends on the rain-fed agriculture with limited use of irrigation for agricultural production and hence rainfall is the single most important determinant of food supply and the country's economy (Belete, 2006). However, the country has immense potential in expanding irrigated agriculture. Despite its irrigation potential, only 5.3% of the potential is currently under irrigational production dominated by small-scale subsistence farming system (Negash and Seleshi 2004).

In spite of the study region's large number of rivers, potential irrigable areas in suitable irrigation methods have not been identified. This calls for a need to conduct detailed irrigation suitability analysis. Hence, the specific objectives of the study were to spatially evaluate and compare land suitability for surface, drip and sprinkler irrigation methods based on FAO evaluation systems for Guang watershed, Ethiopia using GIS tools.

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 $11^{0}35'59''$ to $13^{0}49'12''$ latitude and $35^{0}09'45''$ to $37^{0}46'42''$ 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).

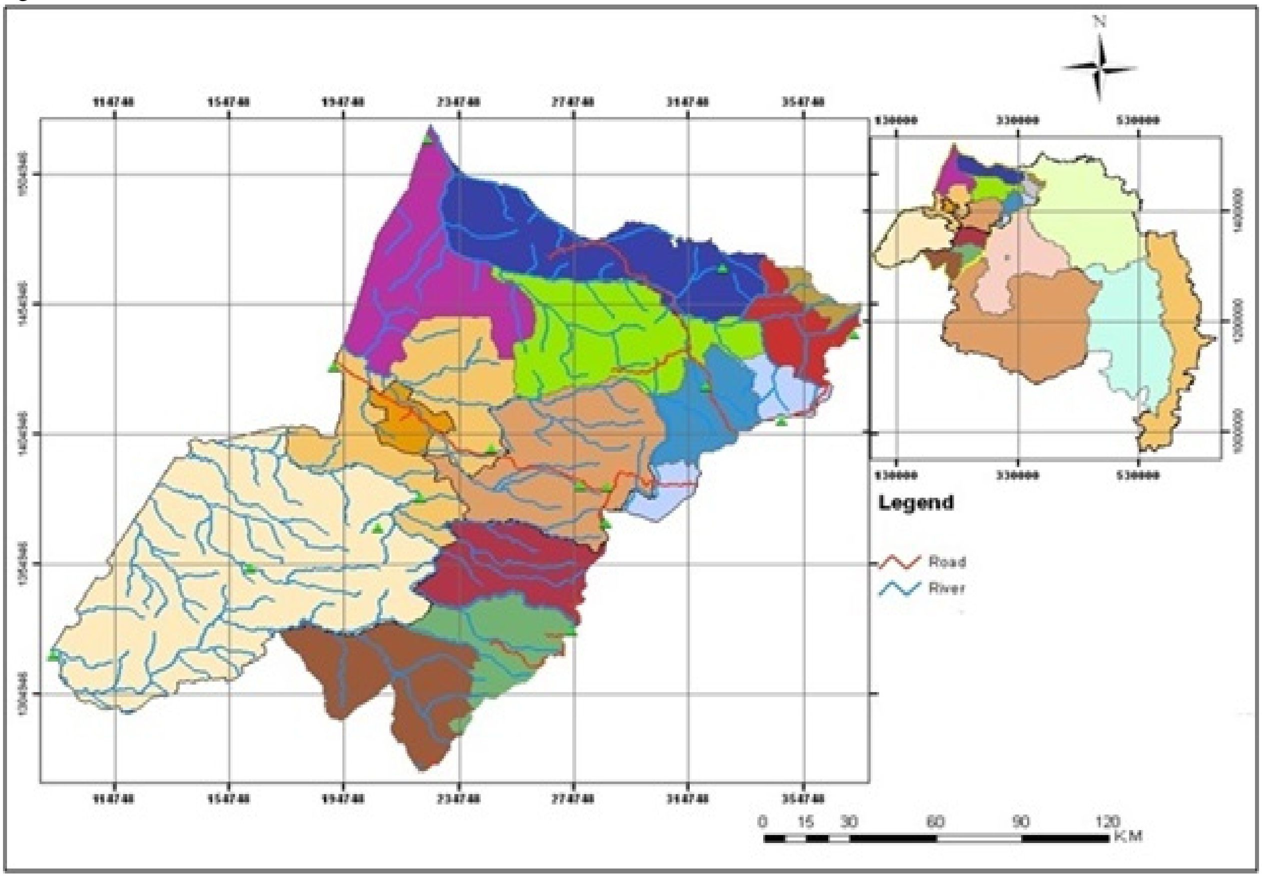

Figure 1: Location map of study watershed

2.3 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 surface soil characterization and irrigation methods 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).

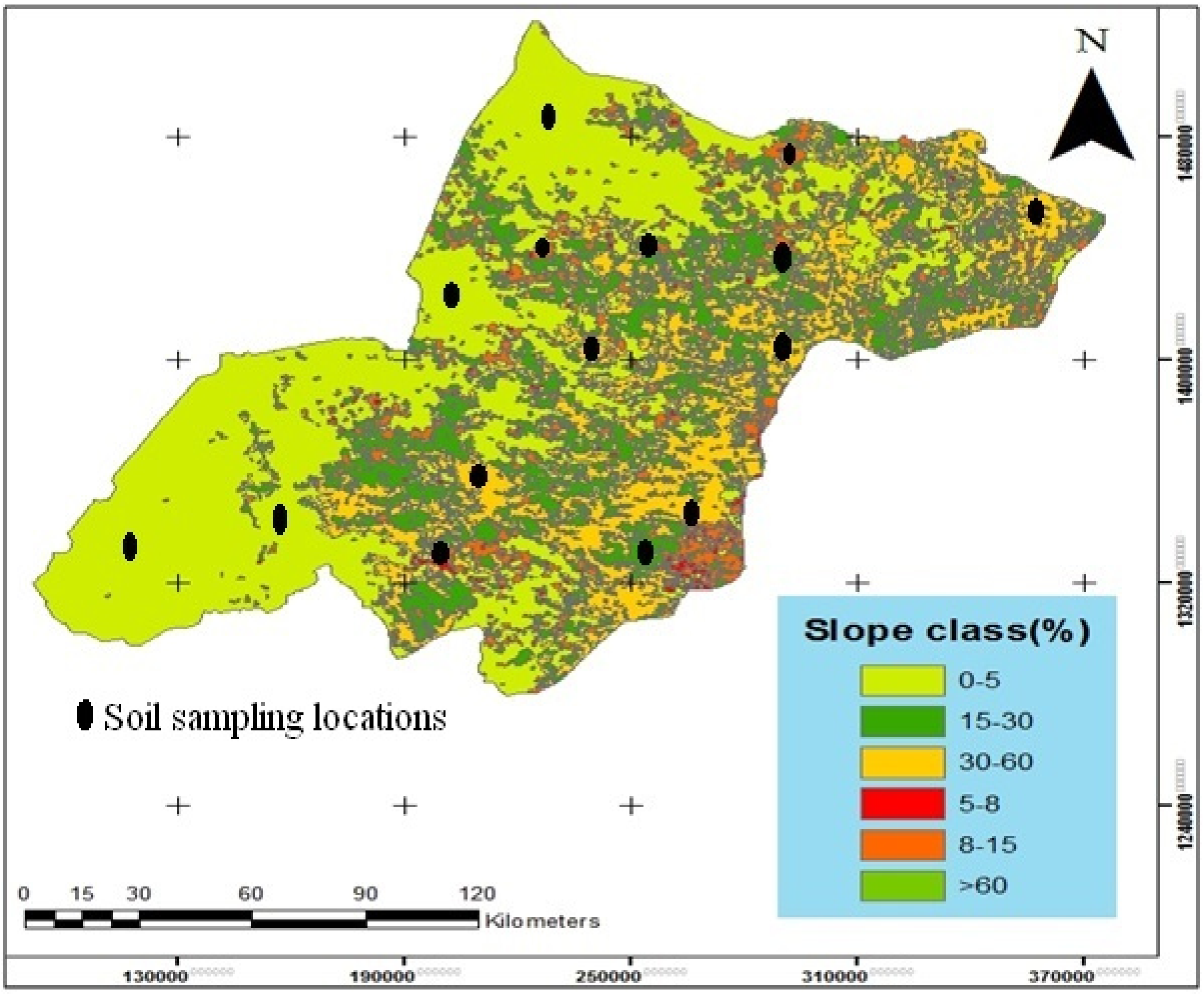

Figure 2: Soil sample locations along slope category

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). In order to assess the salinity hazard of a soil, electrical conductivity (ECe) measurements were carried out. For this, the saturation paste extract was prepared (Gupta, 2004) and ECe was determined by conductivity meter and expressed in millimose per centimeter (mmhos/cm).

Table 1: Soil Physicochemical Analysis

Soil depth (cm)	Sand (%)	Clay (%)	Silt (%)	Textural class	pH (H_2O)	EC_e (mmhos/cm)
>150	24	50	26	Clay	6.8	0.03
>150	44	18	38	Loam	7.2	0.92
>150	38	21	41	Loam	7.1	0.1
>150	32	19	49	Silt loam	7.7	0.26
>150	43	20	37	Loam	6.5	0.15
>150	28	36	36	Clay loam	6.1	0.1
>150	8	48	44	Clay	6.2	0.07
>150	12	68	20	Heavy clay	6.5	0.06
>150	16	54	30	Clay	6.9	0.12
>150	40	18	42	Loam	6	0.09
>150	2	86	12	Heavy clay	6.5	0.17
>150	0	79	21	Heavy clay	7.2	0.07
>150	2	77	21	Heavy clay	8.1	0.11
>150	67	14	19	Sandy loam	6.7	0.14
>150	47	16	37	Loam	7.1	0.04

2.4 Irrigation Land Suitability Evaluation

The irrigation methods (surface and sprinker) were selected through discussion with the key informant farmers and development agents. The evaluation criteria used to address the suitability of the selected irrigation method were soil depth, soil texture, electric conductivity, pH, drainage and slope) factors and rated based on FAO (1976; 1983) and Sys *et al. (*1991 guidelines. These irrigation land use requirements (LURs) were treated as a thematic layer in the GIS database. Digital data of selected land characteristics (LCs) of the region and classifier look up tables for irrigation 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 irrigation LURs.

Land suitability classification was made in an area of 2500 ha by matching between reclassified LCs with irrigation LURs using GIS model builder (Figure 3). The model builder uses maximum limitation method so that the most limiting factor (slope and/or soil characteristics) dictates the final suitability subclass (Sys *et al*., 1991 and Van Diepen *et al*., 1999).

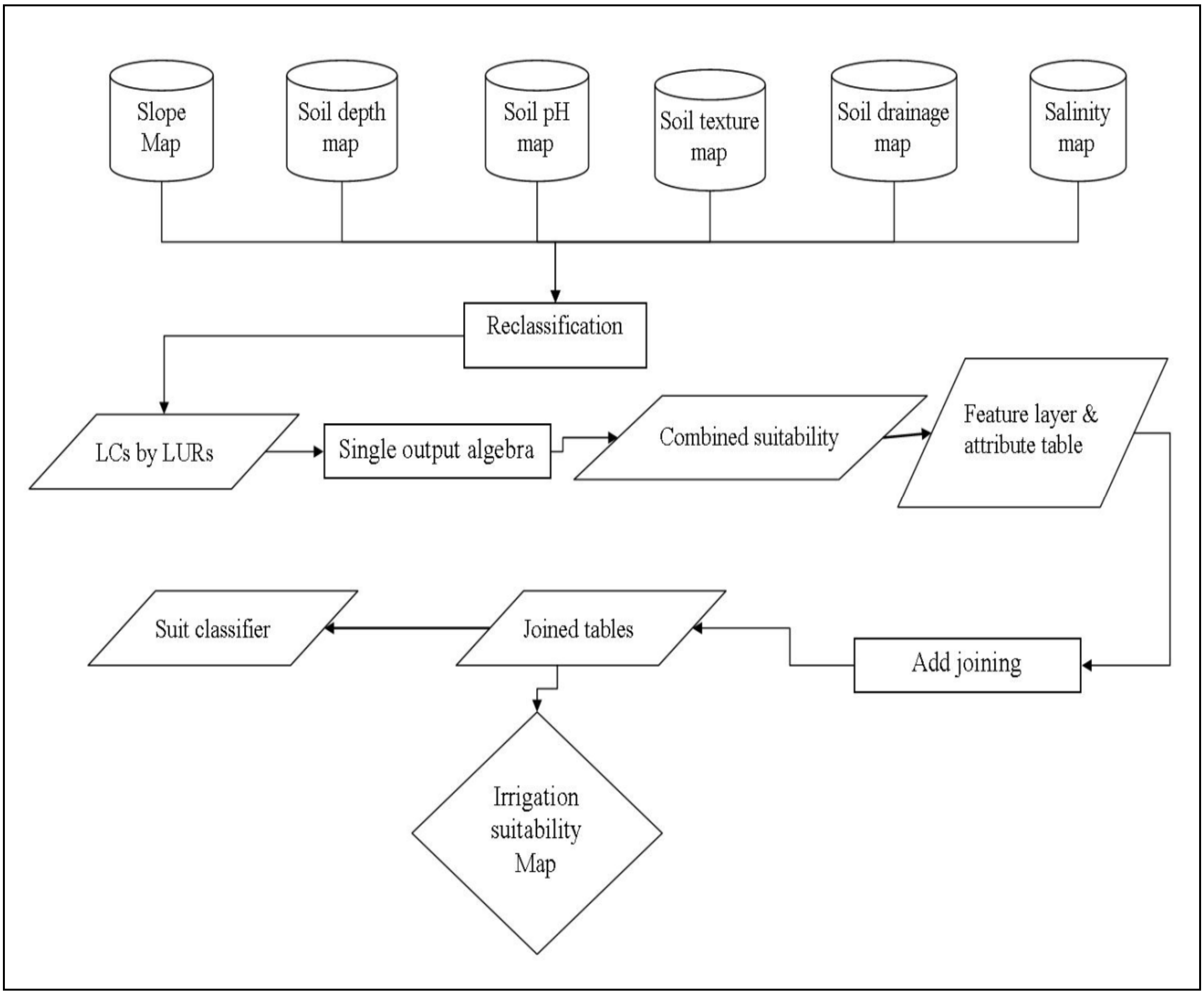

Figure 3: Procedures followed, inputs used and outputs produced in ArcGIS environment

3. RESULTS AND DISCUSSION

The study (Table 1 and Figure 3) showed that 990.25 ha (39.61%) of the study region, Guang watershed were highly suitable (S1) for surface irrigation method. However, 2370 ha (94.8%) of the region was unsuitable (N) for sprinkler irrigation method due to soil salinity, drainage and pH. It also revealed that 635.5 ha (25.42%) and 80 ha (3.2%) land areas were moderately (S2) suitable for surface and sprinkler irrigation methods, respectively. This showed that the surface irrigation method were more efficient than the sprinkler irrigation method to intensively and extensively use the land. This result is similar with the works of Albaji *et al*. (2010a) in the southwest Iran and Bazzani and Incerti (2002) in Morocco. In other study, Bienvenue *et al*. (2003) evaluated that surface irrigation requires heavy textured soils and is limited by drainage.

Table 2: Surface and sprinkler irrigation suitability subclasses and their areas

Suitability class	Limitation	Surface irrigation		Sprinkle irrigation	
		Area (ha)	Area (%)	Area (ha)	Area (%)
S1	-	990.25	39.61	-	-
S2	Slope	125.9	5.036	33.7	1.348
S2	Drainage	509.6	20.384	46.3	1.852
Subtotal for S_2		635.5	25.42	80	3.2
S3	Texture	556.75	22.27	50	2
N	salinity	93.1	3.72	627.5	25.1
N	drainage	98	3.92	987.5	39.5
N	pH	126.4	5.06	755	30.2
Subtotal for N		317.5	12.7	2370	94.8

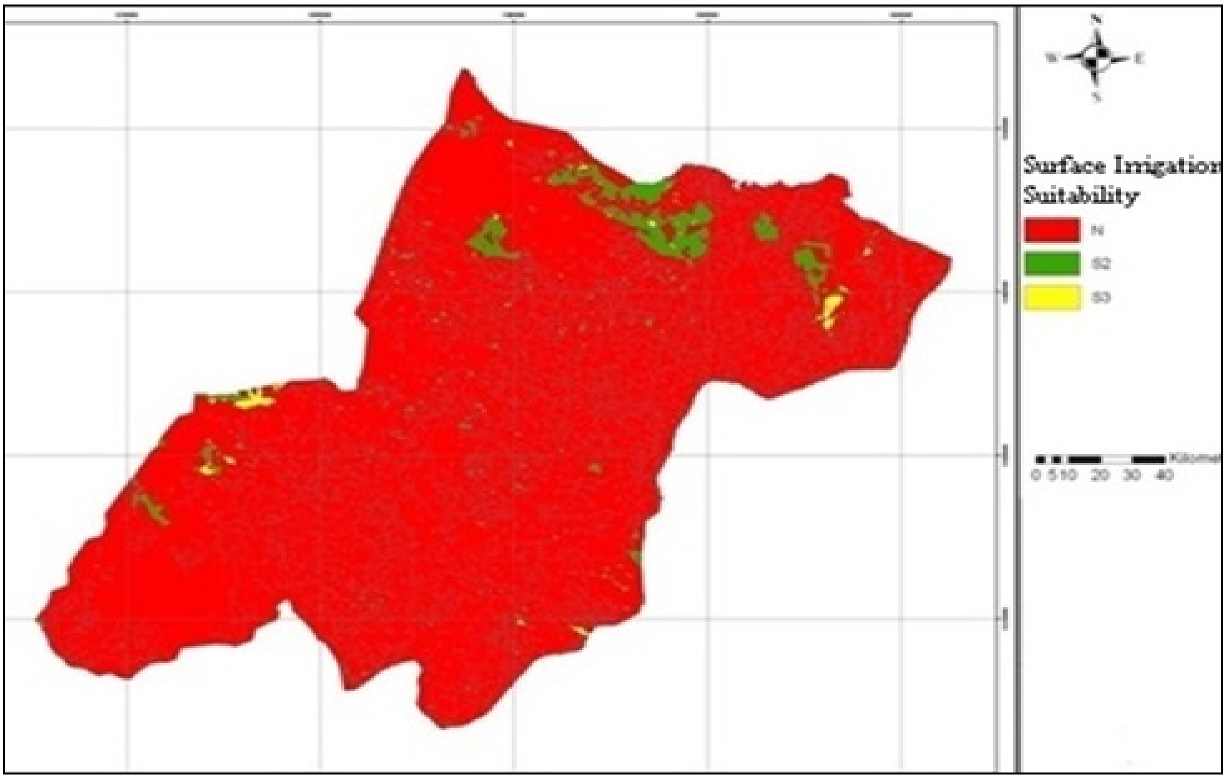

Figure 4: Surface irrigation suitability map

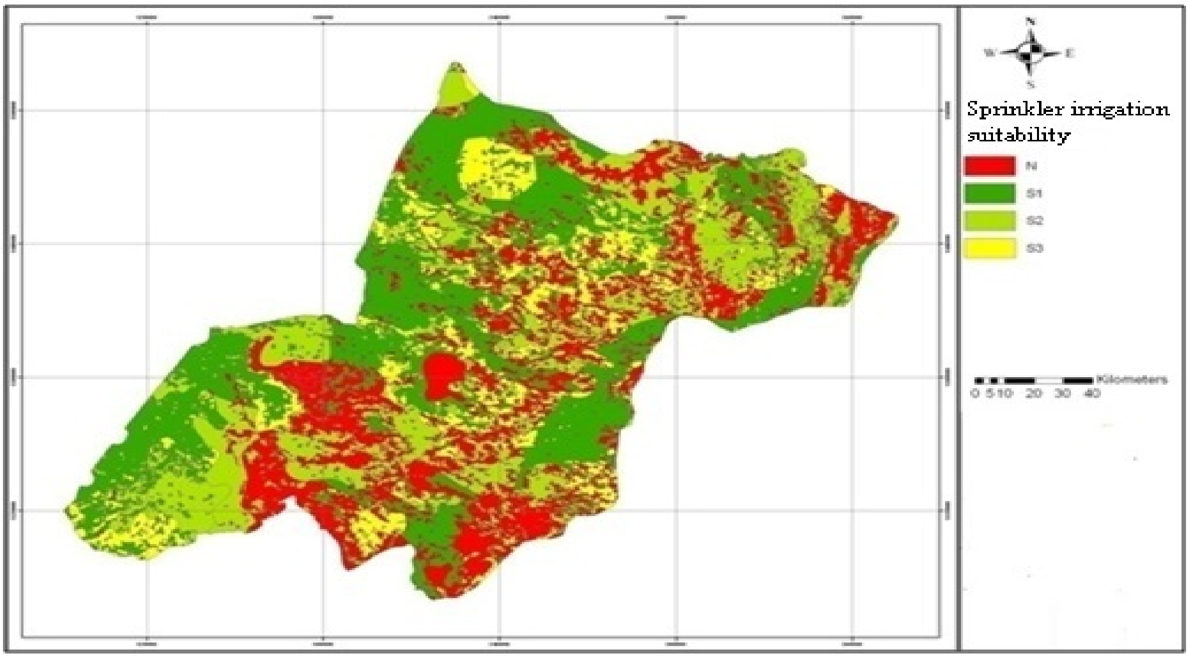

Figure 5: Surface sprinkler irrigation suitability map

4. CONCLUSIONS

Based on the finding of this study, surface irrigation method was more suitable as compared to sprinkler irrigation method in Guang watershed. Soil salinity, drainage and pH were the dominant limiting factors for sprinkler irrigation and slope and soil drainage were limiting factors for surface irrigation method at its moderately suitable level. Further studies are required for more detailed investigation in the region.

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