IJETST-Vol.||2||Issue||7||Pages 2803-2814||July||ISSN 2348-9480 2015

Open access Journal International Journal of Emerging Trends in Science and Technology

Surface Irrigation Suitability Assessment of the Soils of Almanaqil Ridge, Gezira State, Sudan

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Abstract

The main objective of this study was to spatially evaluate land suitability for surface irrigation in the Almanaqil Ridge, Gezira State, Sudan, on an area about 220.000 Acers. The evaluation was based on FAO (1985) guidelines and the method proposed by Sys et al., 1991 (PART I, II, and III). Hundred check (auger) sites and 16 profiles were studied. The area was divided into 3 mapping units. The units are classified according to the American System (Keys to Soil Taxonomy, 2010) in the fallowing families: Fine loamy, mixed, isohyperthermic, TypicHaplustepts (unit1), Fine, mont, superactive, Isohyperthermic, VerticHaplocambids (unit2) and Fine, mont, superactive, isohyperthermic, TypicHaploustert (unit3). The 30 m spatial resolution Digital Elevation Model was used to generate slope by using Spatial Analyst Tool Surface Slope in ArcGIS 9.3 environment. Land characteristics used as criteria were slope class, texture, soil depth, calcium carbonate status, salinity & sodicity and drainage. The irrigation suitability map was compiled by matching between reclassified Land characteristics with irrigation land use requirements (LURs) using GIS tools. The results showed that units 2 and 3 are slightly suitable. This could be due to limitation of the clay texture (vertisolic) and drainage (low infiltration rate) while mapping unit 1 was suitable. The result can assist decision makers in ensuring that lands are used according to their suitability.

Keywords: *irrigation suitability, Soil analysis, GIS and mapping unit.*

Introduction

The estimation of the land capacity for irrigation is basic in plans for development, as irrigated crops constitute the most productive form of agriculture and are especially profitable in arid and semi-arid regions. The characteristics and qualities of the soil, needed in the evaluation related to irrigation, include soil, drainage, hydrology, topography, vegetation, technical problems, economics, and social as well as political matters. Therefore, regional planning of an irrigation project requires multidisciplinary solutions. The system used in this study is a classic, widely used system.

The Land Class is defined as a “category of land having similar physical and economic attributes which affect the suitability of land for irrigation” (McRae and Burnham, 1981). The irrigation suitability classification of the Unites States Bureau of reclamation system (USBR, 1953) establishes six classes to evaluate the suitability of the soils for irrigation. The parameter used and its ranges are reproduced in corresponding tables. To facilitate the reading of the evaluation maps on each cartographic unit, a formula is written in which all the representative data are reflected.

This study aims at Surface irrigation suitability assessment of the Soils of Almanaqil Ridge, Gezira State, Sudan.

The study area

Almanaqil ridge is located, in south west of Gezira Scheme, Gezira State, Sudan. It lies approximately midway between the Blue Nile in the east and White Nile in the west, (latitude 14° 04´ to 14° 29´ N and longitude 33° 97´ to 33° 19´ E). It covers an area of about 220,000 feddan, (Fig.1).

The classification of the soils of the study area was based on the morphology of the soil in the field together with the results of laboratory analysis (Ibrahim, 2013). The soils of the study area were classified, according to the American System of the Soil Classification (Keys to Soil Taxonomy, 2010), into three families, namely; Fine loamy, mixed, isohyperthermic, TypicHaplustepts (unit1), Fine, mont, superactive, Isohyperthermic, VerticHaplocambids (unit2) and Fine, mont, superactive, isohyperthermic, Typic Haploustert (unit3) represents 26.08%, 38.27% and 35.65% of the total area, respectively.

Physically the study area, which is part of the Gezira State, is a plain surface intermitted by dispersed hills. The topography of the study area includes three major units. Namely: highlands and isolated mountains in the southeast, plain area characterized by clayey and sandy soil either along flat or gently sloping areas and valleys (*Wadis*) areas including depositional areas formed of sediment brought down by the Blue Nile from Ethiopian high land. Digital Elevation Module (DEM 30 M and GPS survey level data) was used to produce digital contour map of the study area. Figure 2 showed that the contour line ranged between 380 m to 470 m above sea level. This result indicated high variations in the surface level. That could be divided into three physiographic units' namely; pediment (unit1), piedmont (unit2) and flat plain (unit3) (Ibrahim, 2013). Most of the area is underlain by Basement Complex or Tertiary Basalts both of which provide little ground water, except in the detrital material around the occasional hills together with limited supplies found along joints in the rock (Davies, 1964).

Two distinctive climatic belts are found in the study area. The first one is semi-arid climate found in the north and northeast and characterized by summer rains during July to October. The second one is the dry monsoon climate found in the eastern and southern parts of the state with average rainfall of 250 to 450 mm/ year and maximum mean annual temperature of 47°C, (Meteorology Office-Gezira, 1994).

Methodology

Global Positioning System (GPS) was used to check the locations of the check sites depending on satellite image interpretation, morphological and physical soil properties (color, texture, structure…etc.) (Fig.3). A total of 300 samples (0.5 kg each) were collected from three depths (0-30 cm and 30-60 and 60-90 cm) of the 100 auger sites; another 67 samples (1 kg each) were collected from the 16 profiles. These samples represented most of the existing soil in the study area. Then the soil samples were analyzed using laboratories of the Department of Soil and Environment Sciences, Faculty of Agriculture, U. of K. to determine the flowing chemical and physical properties of the soils:

- pH of saturated soil paste.
  Soil reaction (pH) was measured in the saturated paste using a glass electrode pH-meter Model 7.
- Electrical conductivity of saturation extracts (ECe).
  Electrical conductivity (ECe) was measured in the saturation extract using a conductivity bridge (Model 4460, Hach).
- Soluble cations.
  Soluble cations and anions were determined by: calcium and magnesium by titration with versenate; sodium and potassium by flame photometry (Page *et al.*, 1982).
- Sodium Adsorption Ratio (SAR).
  Sodium adsorption ratio (SAR) was computed from values of soluble sodium, calcium and magnesium.

$$SAR = \frac{[Na^{+}]}{\sqrt{\frac{(Ca^{+2} + Mg^{+2})}{2}}}$$

Where :

SAR: sodium adsorption ratio (mmol+/l)$^{1/2}$
Na: sodium in mmol+/l
Ca: calcium in mmol+/l
Mg: magnesium in mmol+/l

- **Percent calcium carbonate (% CaCO3)**
  Percent calcium carbonate (% CaCO3) was measured using acid neutralization method (Page *et al.*, 1982).
- **Exchangeable sodiumpercentage (ESP).**
  Exchangeable sodium percentage (ESP) was calculated from values of exchangeable sodium and cation exchange capacity, as follows:
  ESP = (Exch. Na/CEC)*100
  Where:
  Exch. Na= Exchangeable sodium (Cmol+/kg soil)
  CEC= cation exchange capacity (Cmol+/kg soil)
- **Particle size distribution**.
  Particle size distribution was determined by the hydrometer method (Klute, 1986).

Note: Analysis of the soil profiles samples were run in both saturation extract and 1:5 soil: water ratios.

In order to evaluate land suitability for irrigation in the study area a parametric system (Sys et al., 1991 PART I, II, and III) was applied. This system is based on the standard granulometrical and physiochemical soil characteristics. The evaluation was applied in order to estimate land suitability for small scale surface irrigation. Only potential land characteristics were taken into account (Tables A1 - AF) but nothing was reported here about effective irrigation possibilities, i.e. about irrigation water availability (sys *et al.*, 1974).

The factors influencing the land suitability for irrigation are divided in the following four groups (Table 2):

- Physical properties, that determine the soil-water relationship such as permeability and available water content (both related to texture, structure, soil depth and calcium carbonates status):
- Chemical properties that interfere in the salinity/sodicity status, such as soluble salts and exchangeable Na;
- Drainage properties;
- Environmental factors, such as slope.

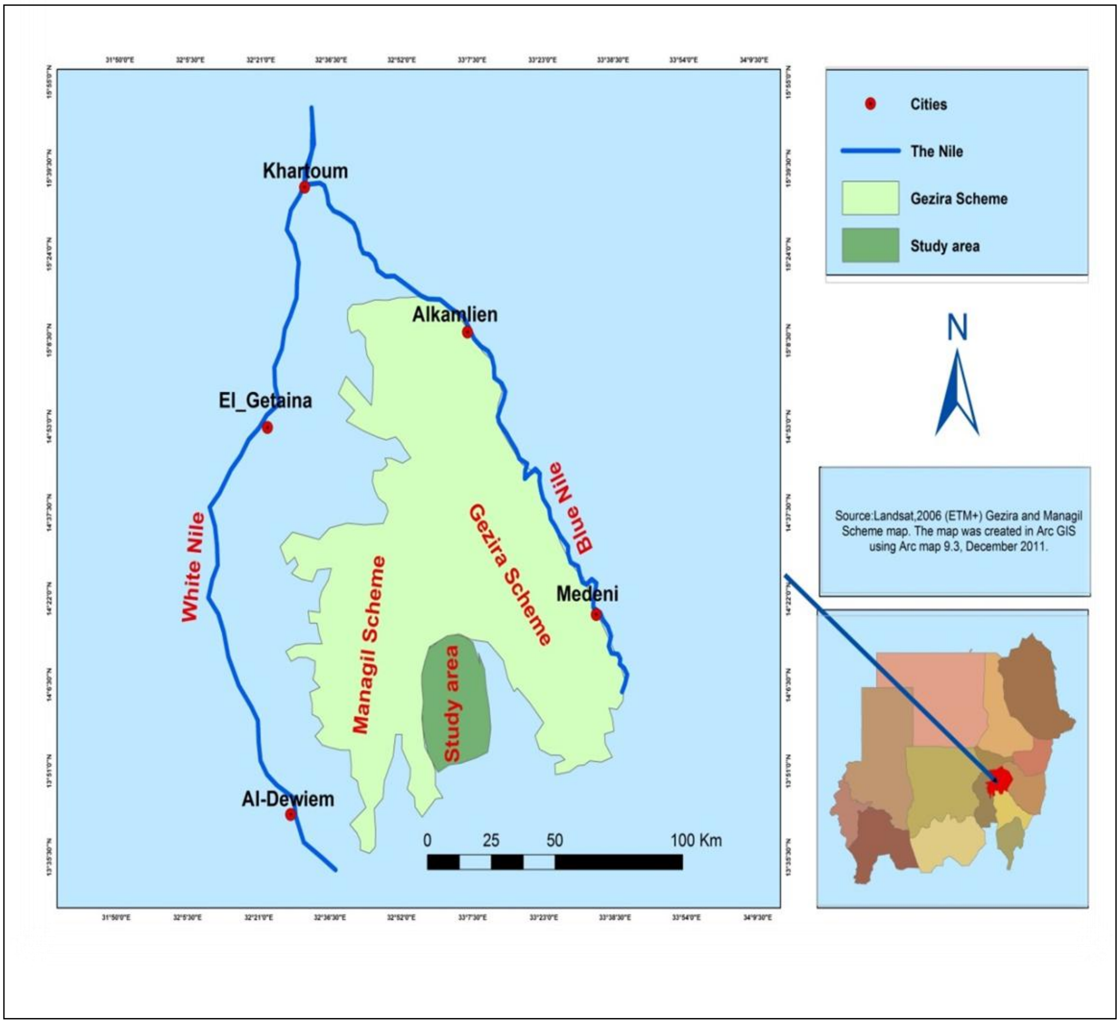

Fig.1: Location map of the study area

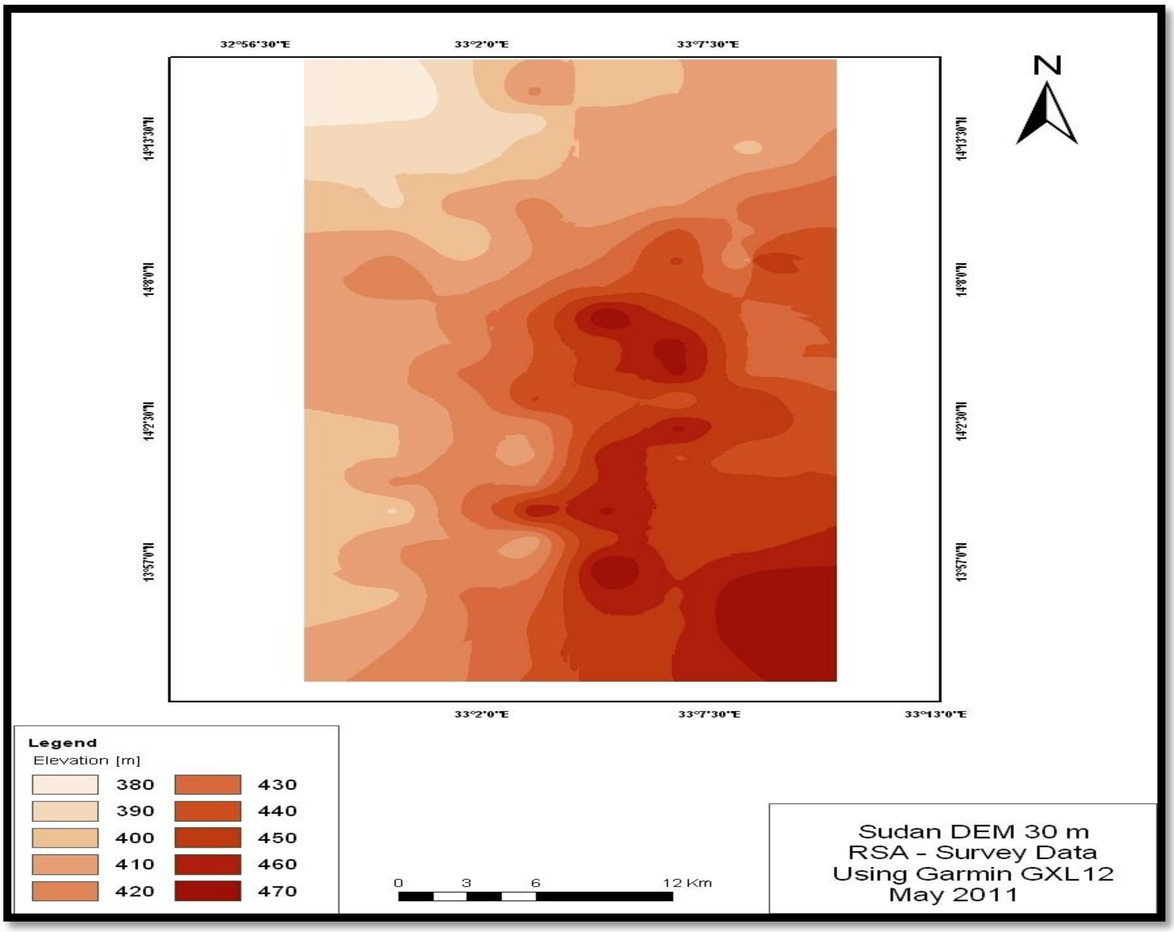

Fig 2: Contour map in the study area

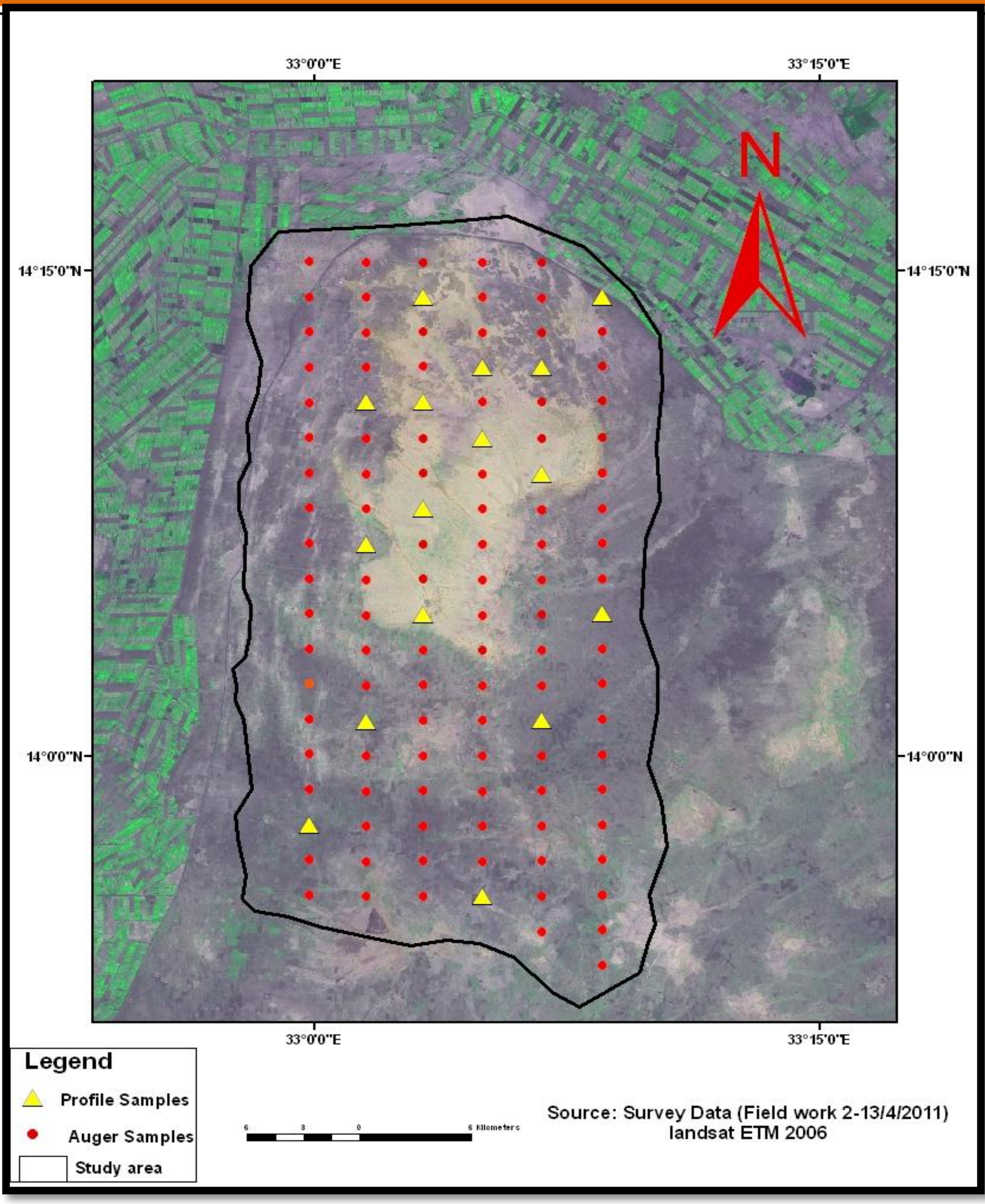

Figure 3: Location of auger and representative soil profiles sites

Table 1A: Rating of soil depth

Soil depth (cm)	Rating
<20	30
20-50	60
50-80	80
80-100	90
>100	100

Table 1B: Rating CaCO3

%CaCO3	Rating
>50	30
25-50	60
10-25	85
0.3-10	100
<0.3	90

Table 1C: Rating of soil texture

Rating of Textural class	<15% Gravel	15-40% Gravel	40-75% Gravel
Clay	65	65	55
Loam	90	80	70
Sand	30	25	25
Silt	90	80	70
Sandy clay loam	95	85	75
Silty clay loam	100	90	80
Loamy sand	55	50	45
Sandy clay	75	65	60
Silty clay	85	95	80
Clay loam	100	90	80
Sandy clay	80	90	75
Silt loam	90	80	70

Table 1D: Rating of slope class

Slope class (%)	Rating	
	Non terraced	Terraced
0-1	100	100
1-3	95	95
3-5	90	95
5-8	80	95
8-16	60	85
16-30	50	70
>30	30	50

Table 1E: Rating of exchangeable sodium with ECe

SAR	Electric conductivity of saturation extract (dS/m)				
	>30	16-30	8-16	4-8	0-4
0-8	80 60*	85 70*	90 80*	95 90*	100 100*
8-15	75 50*	80 60*	85 70*	90 80*	95 90*
15-30	70 40*	75 50*	80 60*	85 70*	90 80*
>30	65 30*	70 40*	75 50*	80 60*	85 70*

(*) Clay, Silty clay, and Sandy clay

Table 1F: Rating of drainage class

other textures	Infiltration rate cm/hr.	Rating	
		Clay, silty clay, sandy clay, silty clay loam	other textures
Excessively drained	> 12.5	100	100
Somewhat excessively drained	4.2-12.5	100	80
Well drained	4.2	95	85
Moderately drained	1.7	80	65
Somewhat poorly drained	0.42	70	55
Poorly drained	0.04	55	45
Very poorly drained	<0.04	50	30

(Kevei and Eltom, 2004).

Table 2: Capability indices for the different capability classes

Capability index	Class	Definition	Symbol
>80	I	Excellent	S1
60-80	II	Suitable	S2
40-60	III	Slightly suitable	S3
20-40	IV	Almost unsuitable	N1
<20	V	Unsuitable	N2

Table 3: Land Suitability for Irrigation

Unit	Profile	Slope	Texture	Soil depth	Ca CO3	Salinity and alkalinity	Drainage			Drainage class	Suitability of irrigation class
1	P1	90	95	90	100	100	85	0.65	II	well drained	suitable
2	P2	95	65	100	100	100	80	0.494	III	Moderately drained	slightly suitable
3	P3	95	65	100	100	100	80	0.494	III	Moderately drained	slightly suitable

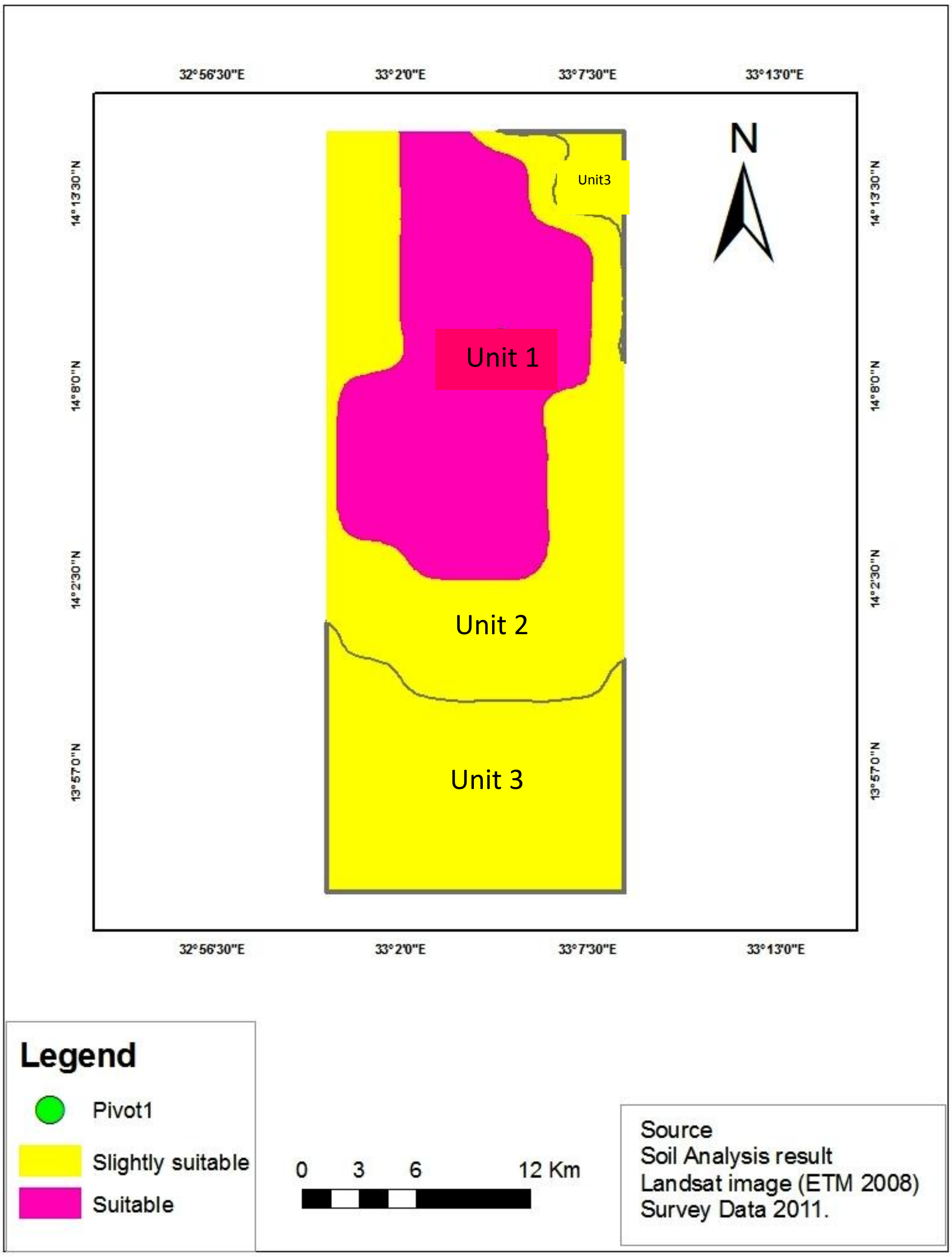

Figure 4: Land suitability for surface irrigation

The different land characteristics that influence the soil suitability for irrigation were rated and a capability index for irrigation Ci, (Table 2) was calculated according to the following formula: Ci = A/100 * B/100 * C/100 * D/100 * E/100 * F/100

Where: Ci: capability index for irrigation; A: rating of soil texture; B: rating of soil depth; C: rating of CaCO3 status; D: salinity/alkalinity rating; E: drainage rating and F: slope rating.

The capability classes were defined according to the value of the capability (or suitability) index Ci, (Sys *et al.*, 1993).For slope class, texture, soil depth, calcium carbonate status, salinity and alkalinity, and drainage, a weighted average was calculated for the upper 100cm of the soil profile then the considered factors were rated (Table 1A to 1F).

Results and Discussion

According to different land characteristics that influence the soil suitability for surface irrigation, two suitability classes for irrigation were identified in the study area (Table 3 and Fig. 4). It's evident that units 2 and 3 are slightly suitable. This could be due to limitation of the clay texture (vertisolic) and drainage (low infiltration rate), while mapping unit 1 was suitable. The effects of soil texture on soil infiltration rate, and consequently the suitability level for irrigation was most limiting. Slope and drainage were not only a limiting factor, but also a reliable criterion derived from the high resolution DEM. Drainage and soil texture produced relatively significant impacts on the result of surface irrigation suitability map.

Conclusions

A GIS based surface irrigation suitability assessment model which integrates with parametric method has been adapted and applied to a land scale irrigation intensification or extensification assessment. It has been found that this model is a valuable and user-friendly tool. The following points can also be drawn from this study:

- Selection of variables or criteria according to local conditions is crucial to evaluation suitability surface irrigation. Criteria considered in the evaluation are also diverse and complex.
- GIS approach allows integration of the spatial variability of terrain and other relevant parameters. The merit of it is found to be beneficial in delineating areas of various suitability ratings for a detailed assessment.

Finally, based on the finding of this study, surface irrigation method was suitable method for the study area. Clay (Vertisols), drainage and slope were the dominant limiting factors for surface irrigation. Further studies are required for more detailed investigation in the region.

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