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RESEARCH ARTICLE

INTEGRATION OF GEOINFORMATICS AND AHP MODEL FOR SOIL SITE SUITABILITY ANALYSIS FOR THE MAJOR CROPS IN SOHAG, EGYPT

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ABSTRACT

Land evaluation procedure given by FAO for soil site suitability for various land utilization types has been used to assess the land suitability for major crops in Sohag Governorate, Egypt. The database on soil, land use/land cover was generated from data derived from Landsat ETM+ remote sensing satellite and soil survey to perform an integrated analysis in the geographic information system environment. Agricultural and non-agricultural lands were delineated using the Decision Tree Classifier (DTC) and non-agricultural areas were masked out for removal from the analysis. Different soil chemical parameters and physical parameters were evaluated for different crops. Subsequently, all of them were integrated using the Analytic Hierarchy Process (AHP) model and GIS to generate the land suitability maps for major crops. Results indicated that the Analytic Hierarchy Process (AHP) model was found to be a useful method to determine the weights. It can deal with inconsistent judgments and provides a measure of the inconsistency of the judgment of the respondents. The GIS is found to be a technique that provides greater flexibility and accuracy for handling digital spatial data. The combination of the AHP method with GIS in our experiment proves it is a powerful combination to apply for land-use suitability analysis.

INTRODUCTION

Suitability of land is assessed considering rational cropping system, for optimizing the piece of land for a specific use (FAO 1976; Sys *et al.* 1991). The suitability is a function of both crop requirements and land characteristics and it is a measure of how well the characters of the land unit match the requirements of a particular form of land use (FAO 1976). Suitability analysis can answer the question (what is grown where?). To assess the suitability of an area, many criteria need to be evaluated (Belka 2005). Multi-Criteria Decision Making (MCDM) or Multi-Criteria Evaluation (MCE) has been developed to improve spatial decision making when a set of alternatives need to be evaluated based on conflicting and incommensurate criteria (Mustafa *et al.* 2011). MCE is an effective tool for multiple criteria decision-making issues (Malczewski 2006) and aims to investigate some choice possibilities in light of not only multiple criteria but also multiple objectives (Cover 1991). In many situations, it is extremely difficult to assign relative weights to the different criteria involved in deciding on the suitability of the land mapping unit for a land-use type. Therefore, it is necessary to adopt a technique that allows an estimation of the weights. One such technique is the Analytical Hierarchy Process (AHP).

Integration of the GIS and AHP can help land-use planners and managers to improve decision-making processes (Malczewski 1999). GIS enables the computation of assessment factors, while MCE aggregates them into land suitability maps. Thus, an integration of GIS and AHP to land suitability analysis expects to produce a promising database.In this study, Analytical Hierarchy Process (AHP) integrated with GIS was applied to evaluate the suitability of the agricultural land of the study area for major crops like wheat, maize,and sorghum using the relevant variables of soil physical and chemical parameters through the MCE technique.

MATERIALS AND METHODS

Study area: Sohag area covers part of Upper Egypt extending from the northern edge of Qena Governorateat latitude 26°07′ N to the southern edge of AssiutGovernorate at latitude 26°57′ N. It is bounded betweenlongitudes 31°20′ and 32°14′ E as in figure (1). The length of the River Nilein the study area reaches 125 km, and the width of thevalley ranges between 16 and 20 km.The study area belongs to the arid region of North Africawhich is generally characterized by hot summer and mildwinter with low rainfall (Figure 2). Air temperature (Figure 3) ranges between36.5°C (summer) and 15.5°C (winter), relative humidityranges between 51% and 61% (winter), 33%, and 41% (Spring), and 35% and 42% (Summer).

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Satellite and ancillary data: In the present study, the Landsat TIRS satellite data were used. The study area is covered by three images viz., (175Path /42 Row, 176 Path /42 Row, and 176 Path /41 Row). The digital data of geo-coded cloud free of three images were downloaded from http://glcf.umd.edu/data/landsat/ that supported by GLCF. Besides,the ASTER sensor onboard the National Aeronautics and Space Administration (NASA) Terra satellite was used for generating DEMs a DEM of the study area with a spatial resolution of 15-m. The ground control points for the geometrical correction of the DEM were obtained using a GPS. This DEM has been used to generate a slope map of the area under study.

METHODOLOGY

The methodology followed in the present study can be classified into four main steps (Figure 4).

Geometriccorrection: Using about 50 easily recognizable Ground Control Points (GCPs) and first polynomial order and nearest neighborhood sampling method provided with ENVI (Environment for Visualizing Images, Research System, Inc.) software (ver.4.8), satellite image was geometrically corrected. The root mean square error (RMSE) was <0.5.

Extraction of the study area and cultivatedlands: The study area (Figure 5) was extracted from the whole image through on-screen digitization of the area of interest (AOI) and masking out using a subset module of ENVI software (ver.4.8). The Normalized difference vegetation index (NDVI), is a potential indicator for crop growth and vigor was used for identifying the cultivated lands. Incorporated (NDVI) with decision tree classifier (DTC), cultivated lands (Figure 6) successfully delineated and used for further analysis. Also, the ASTER images were processed. This includes the generation of mosaicking and sub-image extraction through on-screen digitization of the area of interest (AOI) and masking out using a subset module of ENVI software (ver.4.8). The digital elevation model and slope maps of the study area were generating (Figures 7 and 8).

Ground truth data and samples collection andanalysis

Selection ofprofiles: Based on the variations in the image characteristics of soils of the study area, representative soil samples were collected (Figure9). Horizon wise samples were collected from each profile and analyzed for physical and chemical characteristics using the standard analytical methods as described below.

Analysis of Soil chemical and physical properties: Particle size analysis was determined by the international pipette method described by Black (1965). The moisture retention capacity of the soils at 1/3 and 15 bars was determined by the pressure plate apparatus (Richard 1965). Free $CaCO_3$ was estimated using a rapid manometric method using Collin's Calcimeter (Williams 1949).

The electrical conductivity of the saturated soil paste extract (EC_e) was determined using Elico conductivity meter following the procedure given by Jackson (1973). Soil reaction was determined in soil paste extract using standard pH meter (Jackson 1973). The method described by (Bower *et al.* 1952) was used for the Cations Exchange Capacity (CEC) estimation. Soil organic carbon was estimated using the Walkley and Black wet oxidation method (Jackson 1973). Available nitrogen was estimated using the Kjeldahl distillation method (Subbian and Asija 1956). The available Phosphorus was estimated by the ascorbic acid method described by Watanabe and Olsen (1965) and the concentration was quantified using a spectrophotometer. Available Potassium was extracted by 1*N* ammonium acetate solution at pH~7 as described by Jackson (1973) and determined by flame photometer.

Generation of thematic maps: Thematic maps were generated for each of the soil physical and chemical parameters using IDW interpolation provided in Arc GIS 10.1 software. Inverse Distance Weighted (IDW) interpolation determines cell values using a linearly weighted combination of a set of sample points. The weight is a function of inverse distance. IDW lets the user control the significance of known points on the interpolated values, based on their distance from the output point.

Applying of MCE using spatial AHP procedure: To give relative importance of criteria, sub-criteria, and suitability classes, AHP procedure was used. It involves many main steps:

Generation a hierarchy structure: Malczewski (1999) stated that the relationship between the objectives and their attributes has a hierarchy structure. At the highest level, one can distinguish the objectives and at lower, the attributes can be decomposed. Figure 10 shows the hierarchical structure used in the study.

Development of a comparison matrix at each level of hierarchy: The pair-wise comparison matrix PWCM is a rating of the relative importance of the two factors regarding the suitability of the cropland. For determining the relative importance/weight of criteria, sub-criteria, and suitability classes, the PWCM was applied using a scale with values from 9 to 1/9 introduced by Saaty, (1980). A rating of 9 indicates that with the column factor, the row factor is more important. On the other hand, a rating of 1/9 indicates that relative to the column factor, the row factor is less important. In cases where the column and row factors are equally important, they have a rating value of 1.

Table (1) shows an example of a pair-wise comparison matrix. Figure (10) Hierarchical organization for the criteria considered in the study (Mustafa *et al.* 2011). In the table (1), the diagonal elements are assigned the value of unity (i.e., when a factor is compared with itself). Since the matrix is symmetrical, only the lower triangular half needs to be filled in. The remaining cells are then simply the reciprocals of the lower triangular half (for example, because the rating of pH relative to EC_e is 9, the rating of EC_e relative to pH will be 1/9).

Rating the suitability classes of sub-criteria: Inland suitability analysis, a map represents each evaluation criterion with ordinal values (like S1, S2, S3, N1, and N2) indicating the degree of suitability with respect to a sub-criterion, based on the crop requirements (Sehgal 1999).

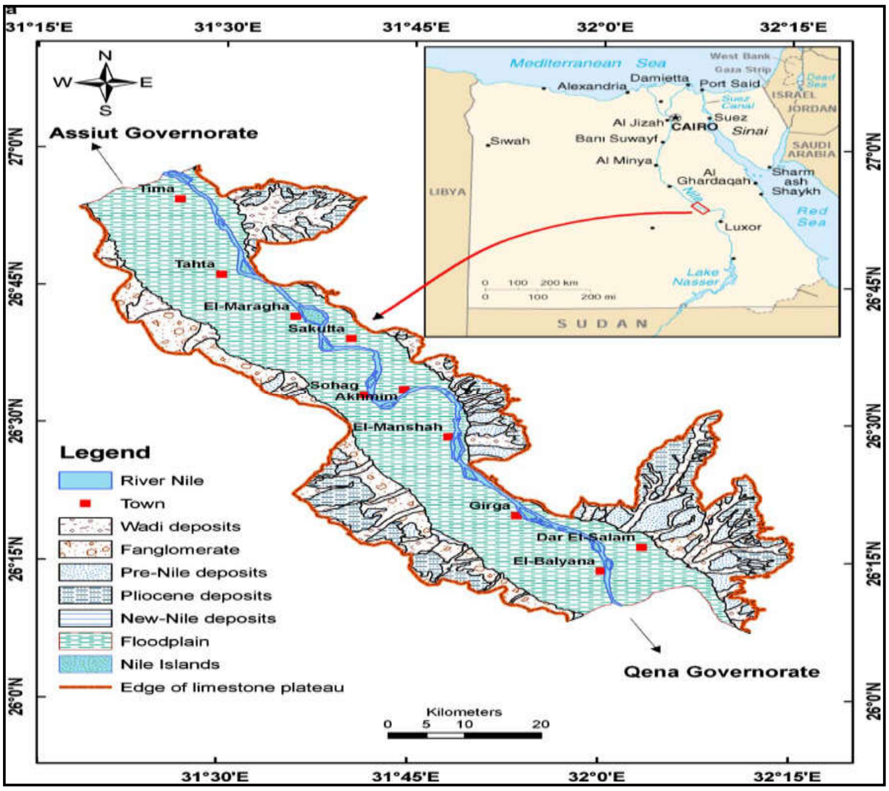

Figure (1) Location of the study area (RIGW 1990)

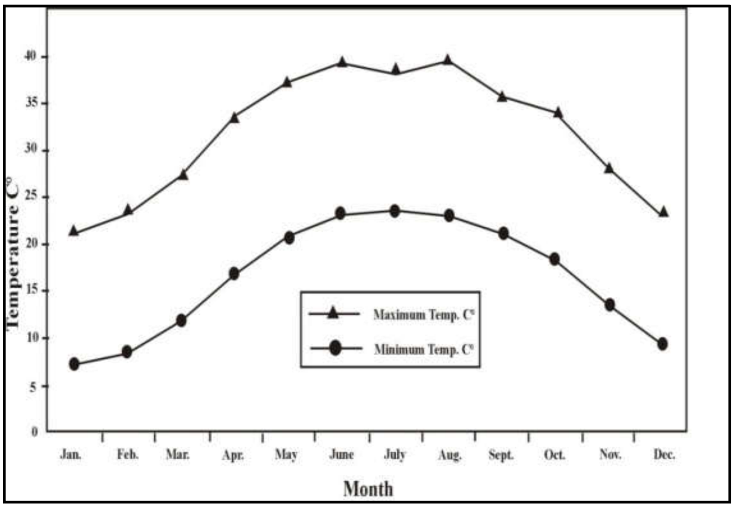

Figure (2) Variations of Temperature in the study area.

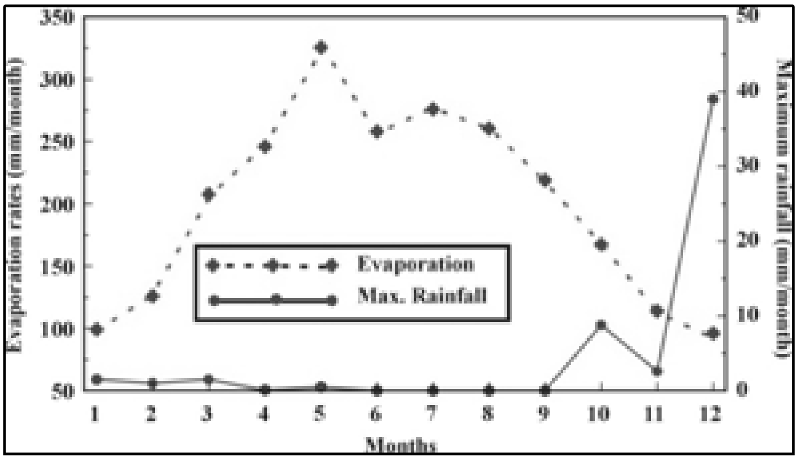

Figure (3) Variations of Evaporation and Rainfall in the study area

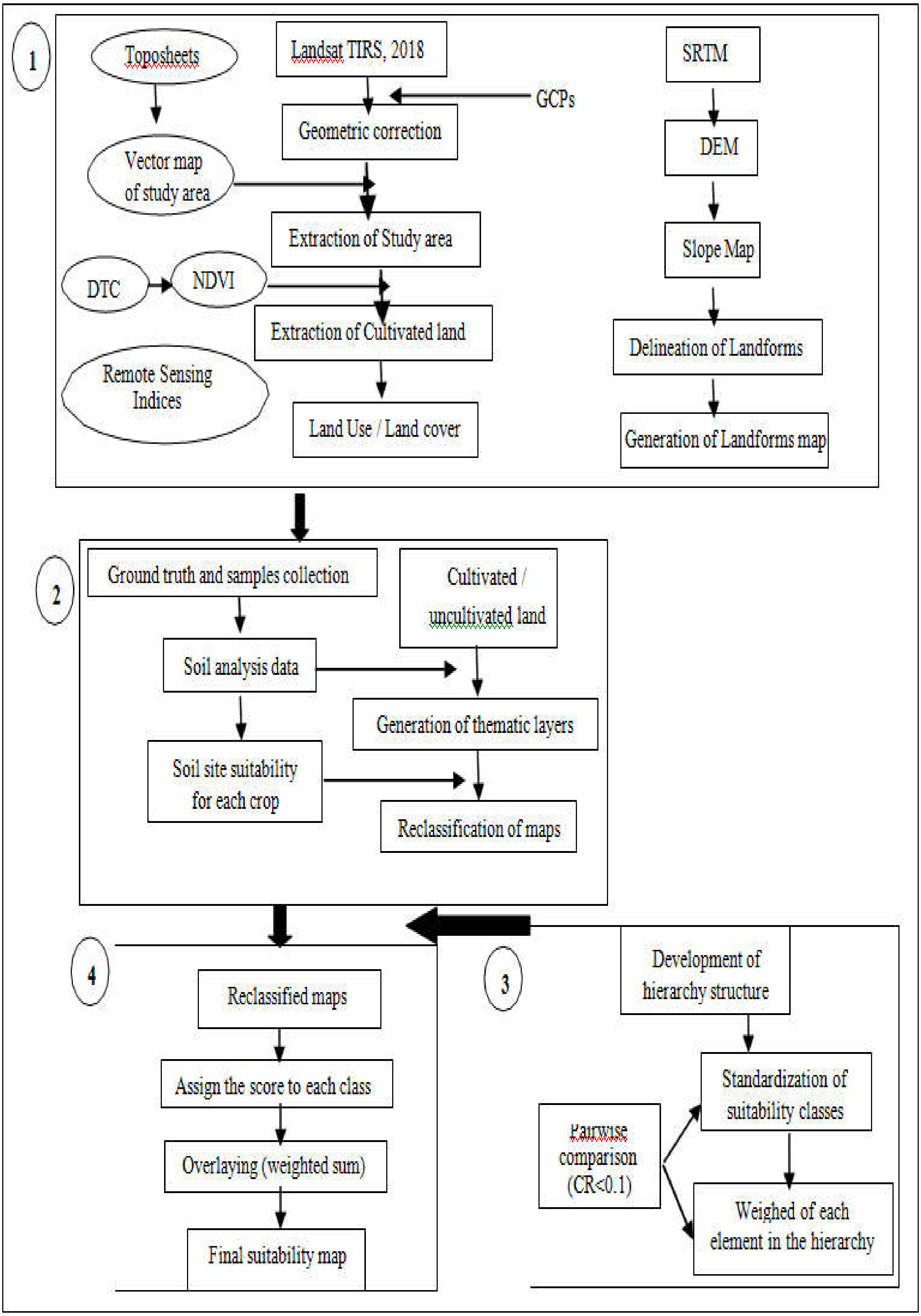

Figure (4) Flowchart of the methodology followed in the study: (1) Extraction of agricultural land, (2) Ground truth and samples collection, (3) Applying MCE, (4) Integration MCE with GIS

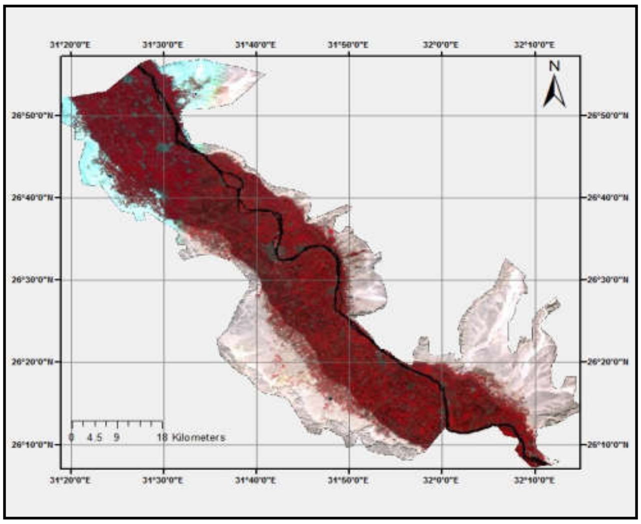

Figure (5) FCC images of the study area generating from Landsat TIRS 2018

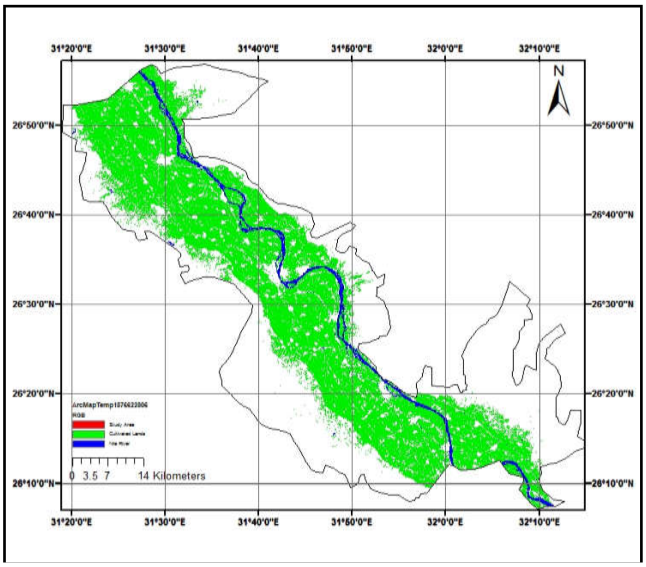

Figure (6) Agricultural land in the study area

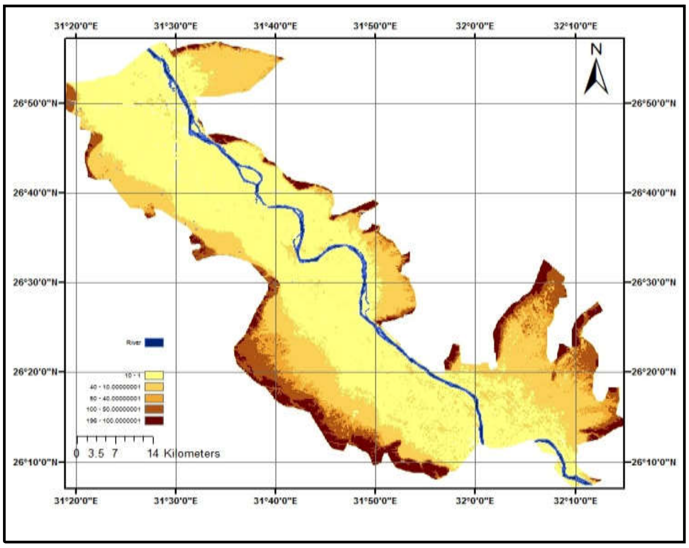

Figure (7) Digital Elevation Model (DEM) of the study area

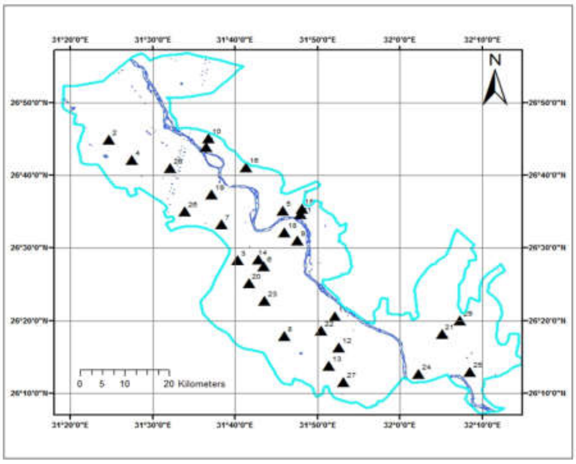

Figure (9) Slope map of the study area

These classes have to be rated, how important is the class S1 concerning a particular sub-criterion to contribute to the final goal? . This process is called the standardization which yields the normalized score for each suitability class (Table 2). It should be noted that for preventing bias thought criteria weighting the Consistency Ratio was used. As a rule of thumb, a CR value of 10% (0.1) or less is considered acceptable.

$$CI = (\lambda - n) / (n - 1)$$
$$CR = CI / RI$$

Where:

λ: The average of consistency vector CI: Consistency Index
CR: Consistency Ratio RI: Random Index

n: The numbers of criteria or sub-criteria in each pairwise comparison matrix

Integration with GIS: Once the standardized thematic layers and their weights were obtained for each crop, the weighted sum overlay within Arc GIS 10.1 was applied to produce the crop suitability map.

RESULTS AND DISCUSSION

Spatial variability of soil properties: Land suitability evaluation, based on soil conditions, requires criterion mostly from the soil attributes. Table (3) represents the main soil parameters used for the generation of the thematic map layers used in the MCDM process for generating the final suitability map for each crop. The important soil parameters are discussed hereunder.

Soil reaction: Soil pH is most useful in soil suitability evaluation and management as it provides information about the solubility and thus potential availability or phytotoxicity of elements for crops subsequently the soil suitability for a specific crop. All the studied profiles were slight to strongly alkaline and the soil pH values ranged between 7.61 and 8.72 (Table 3). The high values of pH would be attributed to high base saturation and exchangeable sodium percentage. Almost of crops don't prefer high pH, thus the soil reaction is considered as one of the limitations that deterred crop growing in the study area. Figure (11) shows the spatial variability of pH throughout cultivated land.

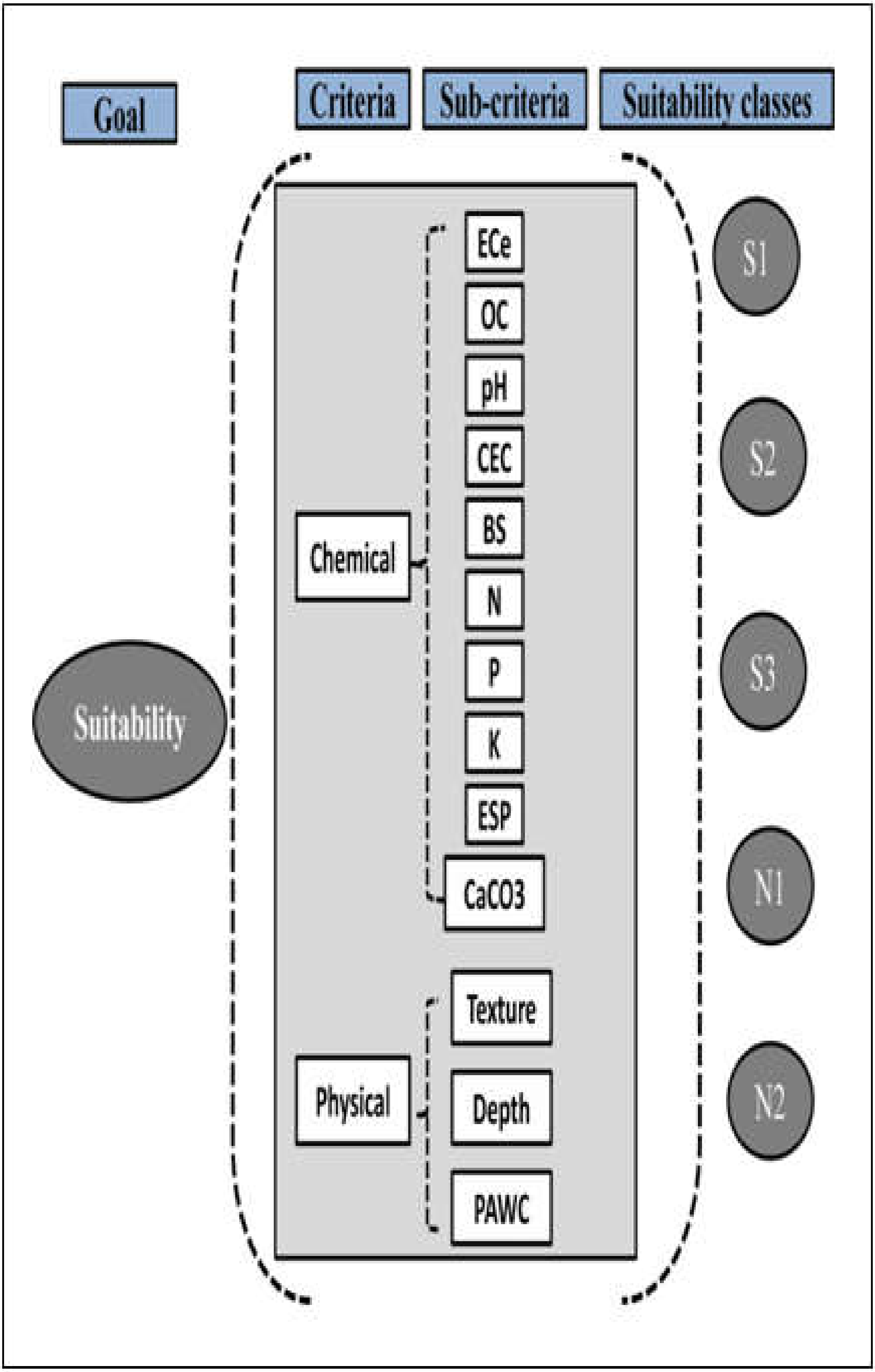

Figure (10) Hierarchical organization for the criteria considered in the study (Mustafa *et al.* 2011)

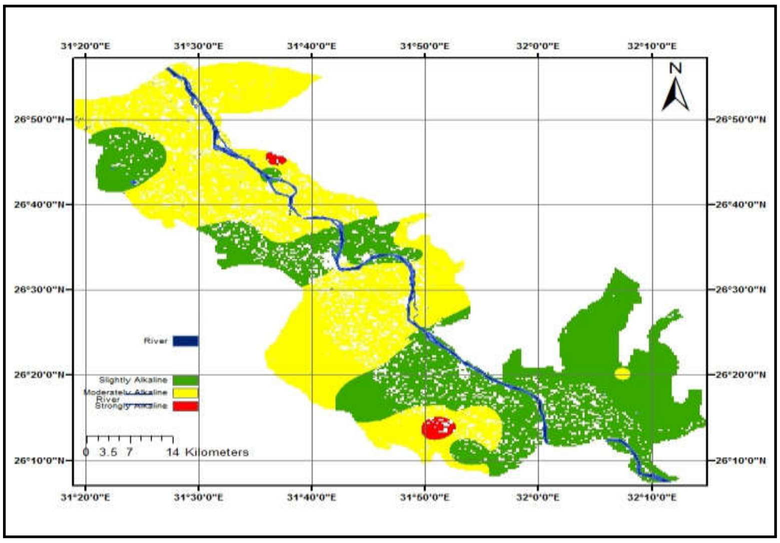

Figure (11) Spatial variability of pH.

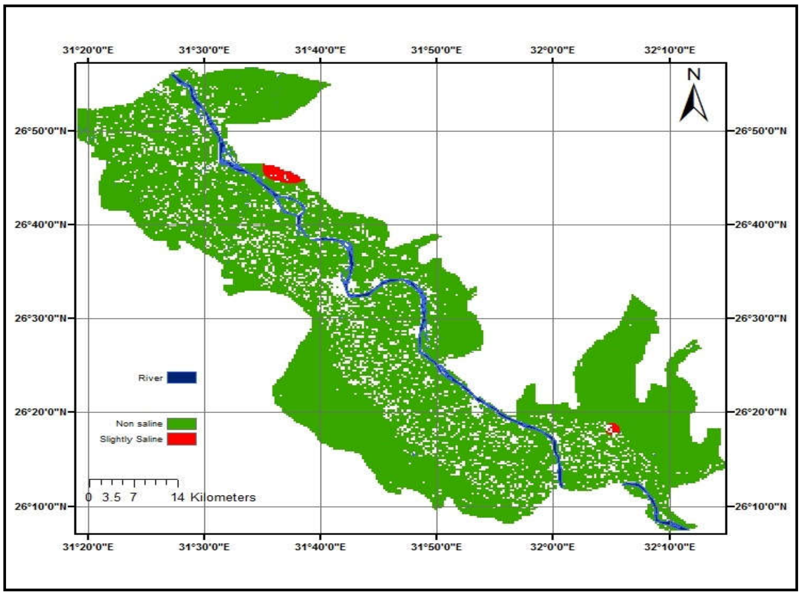

Figure (12) Spatial variability of EC_e

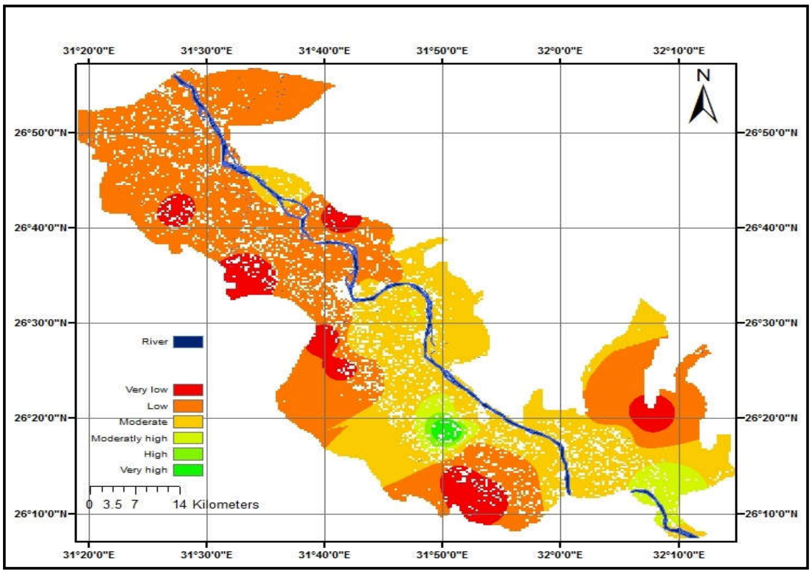

Figure (13). Spatial variability of soil organic carbon.

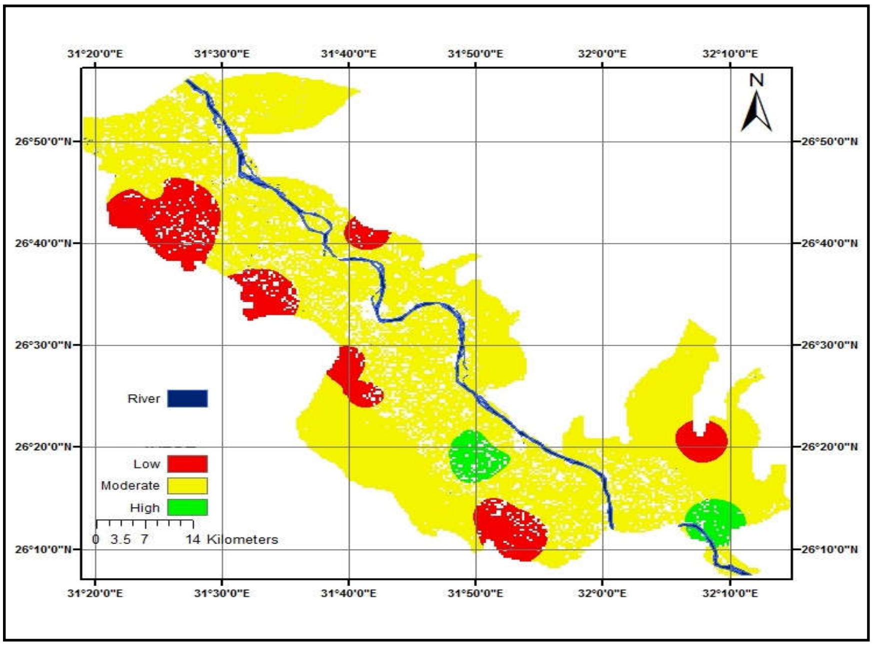

Figure (14). Spatial variability of available N.

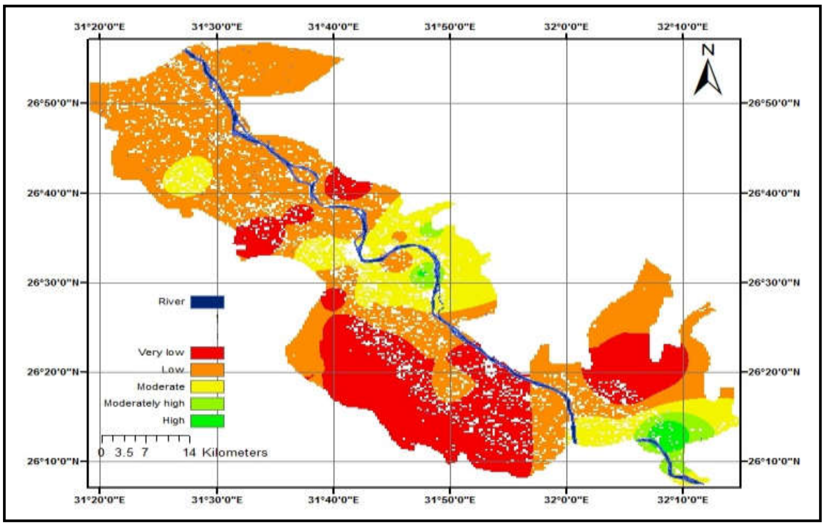

Figure (15) Spatial variability of available P.

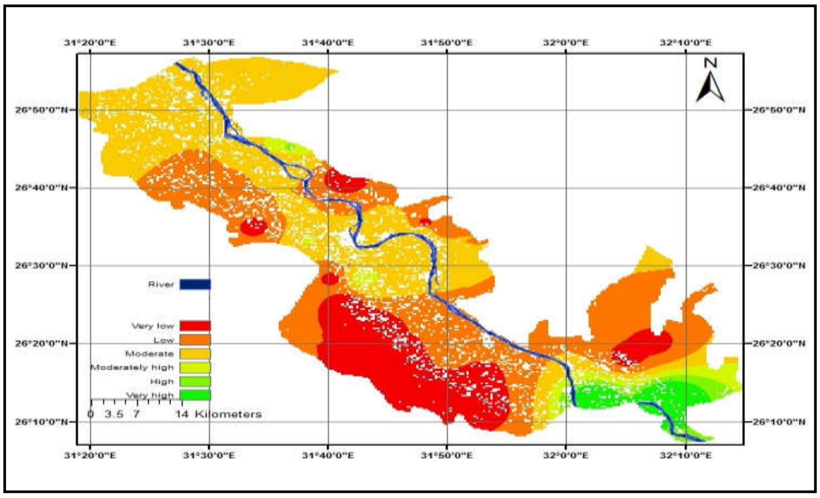

Figure (16) Spatial variability of available K.

Table (1) Weighed the chemical criteria for Maize.

	ECe	pH	ESP	BS	OC	CEC	$CaCO_3$	Weight
ECe	1.0000							0.0472
pH	9.0000	1.0000						0.0999
ESP	0.5000	0.3333	1.0000					0.0334
BS	0.5000	0.3333	1.0000	1.0000				0.0326
OC	5.0000	4.0000	5.0000	6.0000	1.0000			0.2219
CEC	3.0000	6.0000	7.0000	7.0000	1.0000	1.0000		0.2345
$CaCO_3$	5.0000	3.0000	9.0000	9.0000	2.0000	2.0000	1.0000	0.3304
			CR= 0.08					$\sum=1$

Table (2) Rating of suitability classes for Maize

	S1	S2	S3	N1	N2	Score
S1	1.0000					1.0000
S2	0.3333	1.0000				0.5818
S3	0.2000	0.3333	1.0000			0.2540
N1	0.1429	0.1429	0.3333	1.0000		0.1166
N2	0.1111	0.1111	0.2000	0.3333	1.0000	0.0613
			CR = 0.05			

Table (3) Weighted mean of the soil properties of the study area.

Land use		Profile No.	EC_e (dS/m)	pH_e	% O.C	% $CaCO_3$	CEC Cmol(p+) kg^{-1}	% ESP	Available N (mg kg^{-1})	Available P_2O_5 (kg ha^{-1})	Available K_2O (kg ha^{-1})	Texture class
Cultivated	Old cultivated soils	1	0.26	7.65	0.43	0.53	7.43	1.13	447.5	24.16	199.81	sl
		5	0.96	7.61	0.31	1.07	8.01	5.33	366.7	30.18	215.31	scl
		6	0.61	8.21	0.49	4.25	8.93	5.01	487.4	31.14	240.09	scl
		9	0.55	8.14	0.61	3.84	7.88	4.98	567.4	67.20	211.81	scl
		12	1.98	7.82	0.29	1.78	4.03	5.02	352.7	9.06	108.33	sl
		14	0.89	7.88	0.55	4.40	10.98	9.43	527.0	48.55	295.10	c
		17	0.68	7.64	0.46	3.74	6.54	14.73	470.6	9.51	175.70	scl
		18	0.30	7.88	0.60	0.91	8.20	6.75	562.0	19.55	220.42	l
		19	0.28	8.01	0.38	0.62	7.10	1.41	422.8	13.18	190.85	sl
		22	0.46	7.44	1.46	3.00	5.24	12.58	1138.2	24.70	140.85	sl
		24	0.89	7.62	0.58	4.96	17.43	46.93	547.6	43.55	468.48	c
		28	0.32	7.96	0.32	0.78	6.55	1.50	378.7	27.54	176.01	sl
	New reclaimed soils	2	0.47	7.81	0.35	4.77	8.44	8.07	301.8	18.75	226.84	sc
		3	1.29	7.88	0.03	19.65	3.60	8.61	181.3	7.91	96.77	sl
		4	0.31	7.90	0.14	10.59	5.19	3.39	190.4	40.68	139.37	s
		7	0.40	7.68	0.26	3.72	9.16	44.95	334.2	46.00	246.32	scl
		10	3.65	8.54	0.58	4.91	11.72	17.13	564.2	31.79	315.06	cl
		11	0.38	7.66	0.53	2.21	8.42	5.41	511.8	30.84	226.20	scl
		13	0.99	8.72	0.04	31.35	1.73	9.33	201.3	15.43	46.55	s
		15	0.47	8.07	0.50	20.66	2.89	7.09	400.8	63.39	77.71	sl
		20	1.07	8.02	0.06	30.55	1.94	7.04	202.8	5.51	52.07	s
		23	0.45	8.00	0.39	21.13	2.52	7.39	421.0	4.39	67.65	s
		25	0.51	7.77	0.79	3.00	18.05	40.07	686.4	76.83	485.23	c
		27	1.47	7.76	0.03	18.87	3.63	8.27	180.8	3.33	97.44	sl
Un-Cultivated	Barren soils	8	1.94	7.70	0.41	19.16	3.12	8.15	437.2	6.56	83.78	s
		16	1.20	8.05	0.08	33.94	2.25	5.36	211.2	4.49	60.60	s
		21	2.08	7.65	0.45	18.89	3.27	7.86	461.8	2.13	87.76	s
		26	1.61	7.65	0.03	20.22	3.70	7.92	179.3	4.88	99.46	sl
		29	1.29	7.88	0.03	17.67	3.60	8.61	181.3	7.91	96.77	sl

Table 4. The area under different categories of suitability for *rabi* crops

Class	Wheat			Maize			Sorghum		
	%	Km^2	ha	%	Km^2	ha	%	Km^2	ha
N2	11.45	1169.0	116901.6	0	0	0	1.88	191.78	19178.01
N1	15.72	1603.6	160361.9	6.92	706.17	70616.71	12.47	1272.09	127209.19
S3	33.37	3405.4	340546	10.94	1116.49	111648.74	41.56	4240.47	424047.17
S2	33.57	3424.7	342478.7	81.56	8321.37	832137.43	41.45	4229.07	422907.39
S1	5.88	600.11	60011.82	0.58	58.97	5897.11	2.64	269.58	26958.24
Total	100	10203	1020300	100	10203	1020300	100	10203	1020300

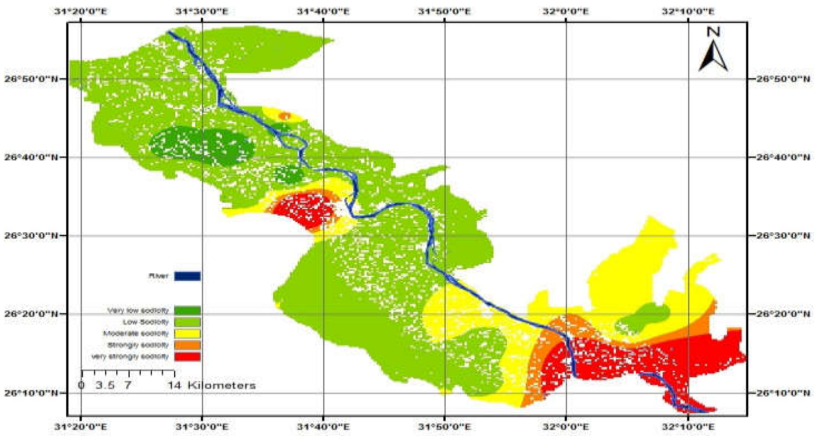

Figure (17) Spatial variability of ESP

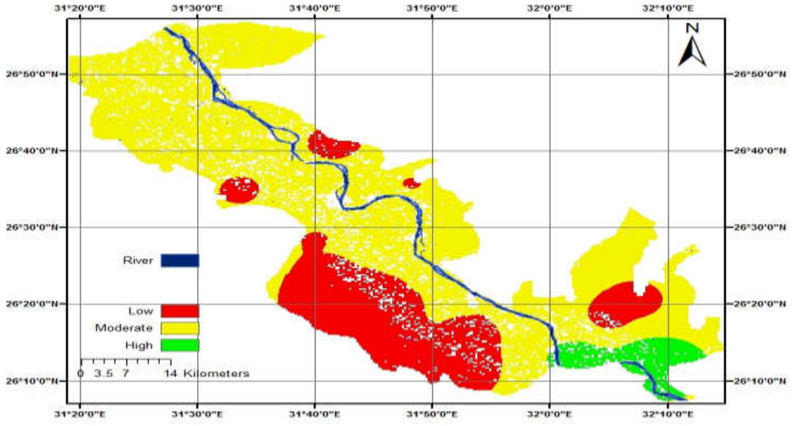

Figure (18) Spatial variability of CEC

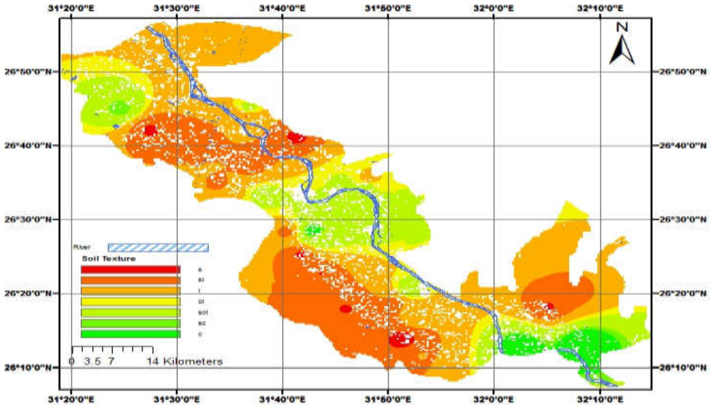

Figure 19. Spatial variability of soil texture

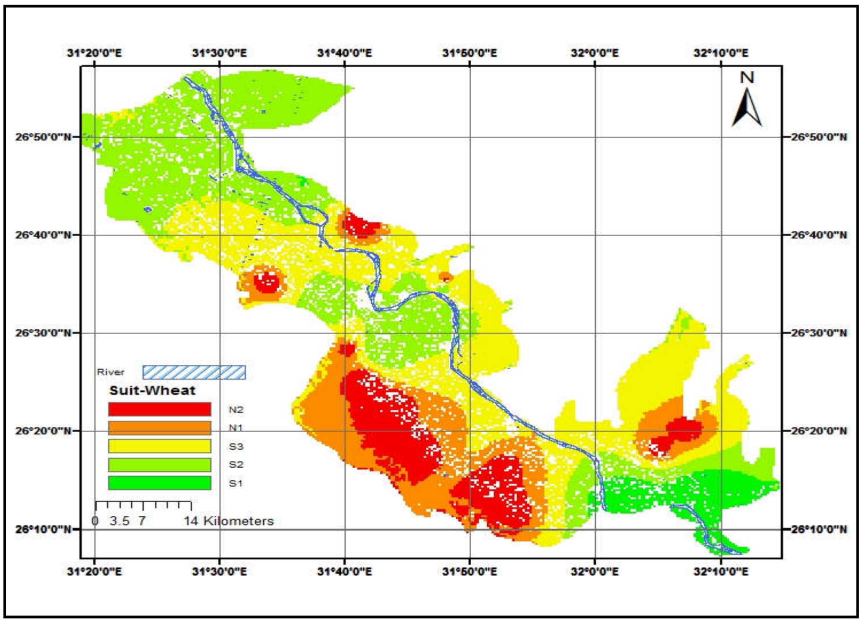

Figure (20) Suitability map of wheat

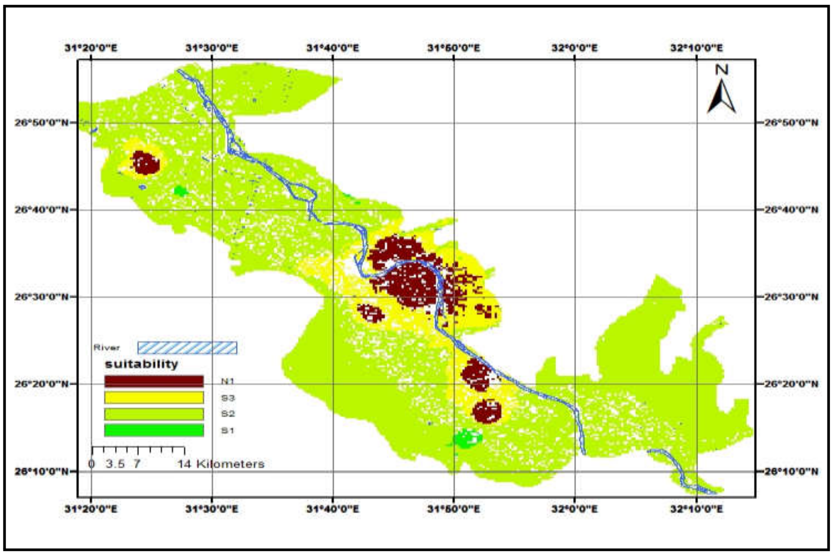

Figure (21) Suitability map of maize

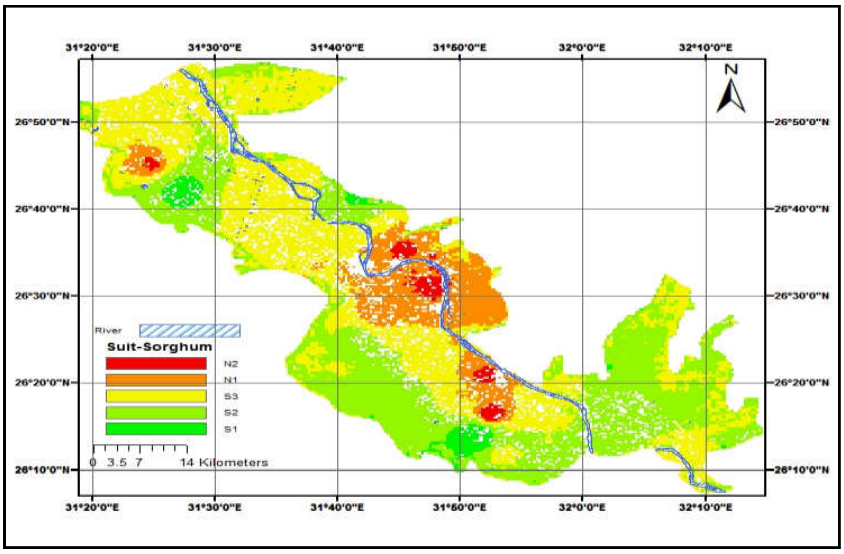

Figure (22) Suitability map of sorghum.

Electrical conductivity (EC_e): It is well known that the salt-affected soils usually occur in arid and semi-arid regions owing to the high evaporation rate. Salt affected soils negatively affected plant growth in several ways. In addition to specific ion toxicities such as Na, Cl, and B; causing direct injury to plants. The spatial variability of EC_e is given in Figure (12). Data in Table (3) suggesting that the soils are Non to slightly saline as the EC_e values ranged between 0.26 and 2.08.6 dS m^{-1}.

Organic carbon: Soil organic carbon (O.C) is important for maintaining micronutrient cations in available form and complexing Al in less phytotoxic form. Besides, it has a high water-holding capacity hence minimizing the effects of moisture stress. Generally, the OC content of all profiles was very low to very high, and almost all of the profiles were low to very low (Table 3). This may be due to the prevalence of tropical conditions where the degradation of organic matter occurs at faster rates coupled with low vegetation cover, thereby leaving less organic carbon in the soils (Nayak *et al.* 2002). The spatial variability of soil organic carbon is given in Figure (13).

Available nitrogen (N): The available N values varied from 179.3 to 1138.2 mg kg^{-1} suggesting that the soils having high to low available N. Low amount of organic carbon could be the significant factor affecting the amount of available nitrogen (Prasuna Rani *et al.* 1992). Subsequently, low available N decreases the suitability of soils for growing many crops. The spatial variability of available N is given in Figure (14).

Available phosphorus (P): The spatial variability of available P is given in Figure 15.
The available phosphorus in the surface layers varied from a minimum value of 3.33 to a maximum of 76.83 kg ha^{-1}.

Available potassium (K): Available K varied from 46.55 to 468.48 kg ha^{-1}. This suggests that most of the profiles contain a very low to medium amount of available potassium (Figure 16).

Exchangeable sodium percentage (ESP): ESP varied between 2.13 and 46.9 % in the studied soils. The highest values were found in profiles No. 7, 24, and 25. Also, most of the study area is characterized as low to very low ESP. This factor is considered as one of the important limitations in the area under study hence it renders some areas under no suitable class. Figure 17 shows the spatial variability of ESP. The CEC varied from 1.94 to 18.05 cmol (p+) kg^{-1} indicates that almost all of the studied soils are low to medium in CEC. The spatial variability of CEC is given in Figure 18.

Soil texture: The texture is one of the important parameters of soil. Most of the physical characteristics of the soil depend upon texture class. Seven texture classes occurred in the study area *viz.* sandy (s), sandy loam (sl), loam (l), clay loam (cl), sandy clay loam (scl), sandy clay (sc) and clay (c). The spatial variability of soil texture classes is given in Figure (19).

Soil suitability for different crops: Three major crops i.e. wheat, Maize, and sorghum were evaluated for growing in the study area. The data in Table (4) represent the area under different suitability classes and the results are discussed below.

Wheat: The major limitations faced by wheat cultivation in some parts in the area under study are due to low potassium, low organic carbon, and subsequently low available nitrogen. The data in Table (4) and Figure (20) indicated that about 11.45% and 15.72% of the area are placed under N1 and N2 classes respectively. Approximately, an equal area falls under S2 and S3 classes whereas 5.88% of the area falls under the S1 suitability class.

Maize: Around 81.568% of the area is moderately suitable for maize cropping while 10.94% is marginally suitable. Approximately, 6.92% of the area falls under N1 and finally small area (0.58%) belongs to S1 classes. The major limitations are low organic carbon, potassium, nitrogen, and high ESP and pH (figure 21).

Sorghum: The major limitations encounter the sorghum cropping in some parts in the area under study is due to low potassium, low organic carbon, and subsequently low available nitrogen.
While high pH and ESP, are limiting factors in other areas. The data in Table (4) indicated that an equal area of about 41.45% and 41.56% are placed under S2 and S3 classes respectively. About 12.47% is temporarily unsuitable for growing sorghum and about 2.64% is highly suitable (Figure 22).

Conclusion

The Analytic Hierarchy Process (AHP) method commonly used in multi-criteria decision-making exercises was found to be a useful method to determine the weights. It can deal with inconsistent judgments and provides a measure of the inconsistency of the judgment of the respondents.
The GIS is found to be a technique that provides greater flexibility and accuracy for handling digital spatial data. The combination of the AHP method with GIS in our experiment proves it is a powerful combination to apply for land-use suitability analysis.

Future Research Direction

For further suitability studies, the selection of more factors likes soil, climate, irrigation facilities, and market infrastructure and socio-economic should be proposed. It is important to create the soil databases and land information system, including soil types, soil fertility, terrain, current land use status, climate, slope, vegetation cover, soil erosion, land unit map. This well gives much room for progress and improves the land suitability analysis.

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