Land Suitability Analysis for Different Crops: A Multi Criteria Decision Making Approach using Remote Sensing and GIS

A. A. Mustafa[1], Man Singh[1], R. N Sahoo[2], Nayan Ahmed[3], Manoj Khanna[1], A. Sarangi[1] and A. K. Mishra[1]

[1]Water Technology Center, [2] Division of Agricultural Physics, [3]Division of Soil Science and Agricultural Chemistry

Indian Agricultural Research Institute, New Delhi-110 012

(Email: a_mustafa32@yahoo.com)

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 different crops and for generating cropping pattern for *kharif* (summer) and *rabi* (winter) seasons in Kheragarah *tehsil* of Agra. Kheragarah *tehsil* suffers from many types of land degradation such as such as salinity, watelogging, ravines, degraded hills and rock quarries (AIS & LUS, 2000). The database on soil, land use/land cover was generated from data derived from IRS -P6 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 for removal from future analysis. Different soil chemical parameters and physical parameters were evaluated for different crops. Subsequently all of them were integrated using a multi criteria decision making and GIS to generate the land suitability maps for various crops. *Kharif* and *rabi* season cropping patterns maps were developed by integrating crop suitability maps for the winter and summer seasons separately. Results indicated that about 55 % is highly suitable (S1) for sugarcane and 60%, 54% and 48 % of the area are moderately suitable (S2) for cultivation pearl millet, mustard and rice respectively. 50 % of the area is found to be marginally suitable (S3) for growing maize. It was also found that better land use options could be implemented in different land units as the conventional land evaluation methods suffer from limitation of spatial analysis for the suitability of various crops.

Introduction

Suitability of land is assessed considering rational cropping system, for optimizing the use of a piece of land for a specific use (FAO, 1976; Sys *et al.*, 1991). 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 (FAO 1976). Suitability analysis can answer the question (what is to grow where?). In order to define the suitability of an area for a specific practice, several 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 on the basis of conflicting and incommensurate criteria. MCE is an effective tool for multiple criteria decision-making issues (Malczewski, 2006) and aims to investigate a number of choice possibilities in light of not only multiple criteria but also multiple objectives (Cover, 1991).

Many of GIS-based land suitability analysis approaches are recently developed such as Boolean overlay and modelling for land suitability analysis. However, these approaches lack a well-defined mechanism for incorporating the decision-maker's preferences into the GIS procedures (Malczewski, 2006). This may be solved by integrating GIS and MCE methods.

Integration of the GIS and MCE 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 a land suitability maps. Using GIS based multi criteria evaluation approach, Baniya (2008) evaluated land suitability for vegetable crops in Nepal. He found that the MCE along with GIS is a useful tool for integration of socio economic and environmental data. Also it is a promised tool for identifying the strength and limitation of land for horticultural crops. Kanlaya et al. (2009) evaluated the land suitability for cultivation of sugarcane and cassava crops in Kanchanaburi province, Thailand. To achieve this goal, MCDM integrated with the FAO framework (1976) for soil site suitability was used to assess suitable areas for growing these crops. Khoi and Murayama (2010) delineated the suitable cropland areas by applying a GIS based multi criteria evaluation approach in the Tam Dao National Park Region, Vietnam.

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 some *rabi* crops like wheat mustard, barley and sugarcane and some *kharif* crops such as rice, cotton, maize, pearl millet and sorghum using the relevant variables of soil physical and chemical parameters through the MCE technique. Also for crop versatility, multi crops suitability maps for *rabi* and *kharif* crops have been generated.

Materials and methods

Study area

Covering an area of about 80,000 ha, Kheragarh *tehsil* (Fig.1) extending from 26° 44′ 31.43″ to 27° 4′ 7.80″ N and 77° 27′ 21.27″ to 78° 7′ 22.42″ E of Agra district, Uttar Pradesh, India is defined as study ares. The area was characterized by hot dry sub-humid to semi-arid transition with intense hot summer, cold winter and general dryness through the year except during July and September. The mean annual air temperature varies from 34° to 46° C in summer rising to 50°C in the month of June. The winter (December- February) average temperature ranges from 6.5 to 13° C dropping to minimum 4° C during January. The area receives mean annual rainfall ranging between 600 to 1000 mm which is mostly received during southwest monsoon period followed by the post monsoon period from October to November. Unfortunately, the mean rainfall in winter is considered as insufficient for growing up *rabi* crops Neem (*Azadirachta indica*), Babul (*Acacia arabica*), Dhak (*Butea monosperma*) and Faras (*Tamarix sp.*) are the predominant species among the natural vegetation.

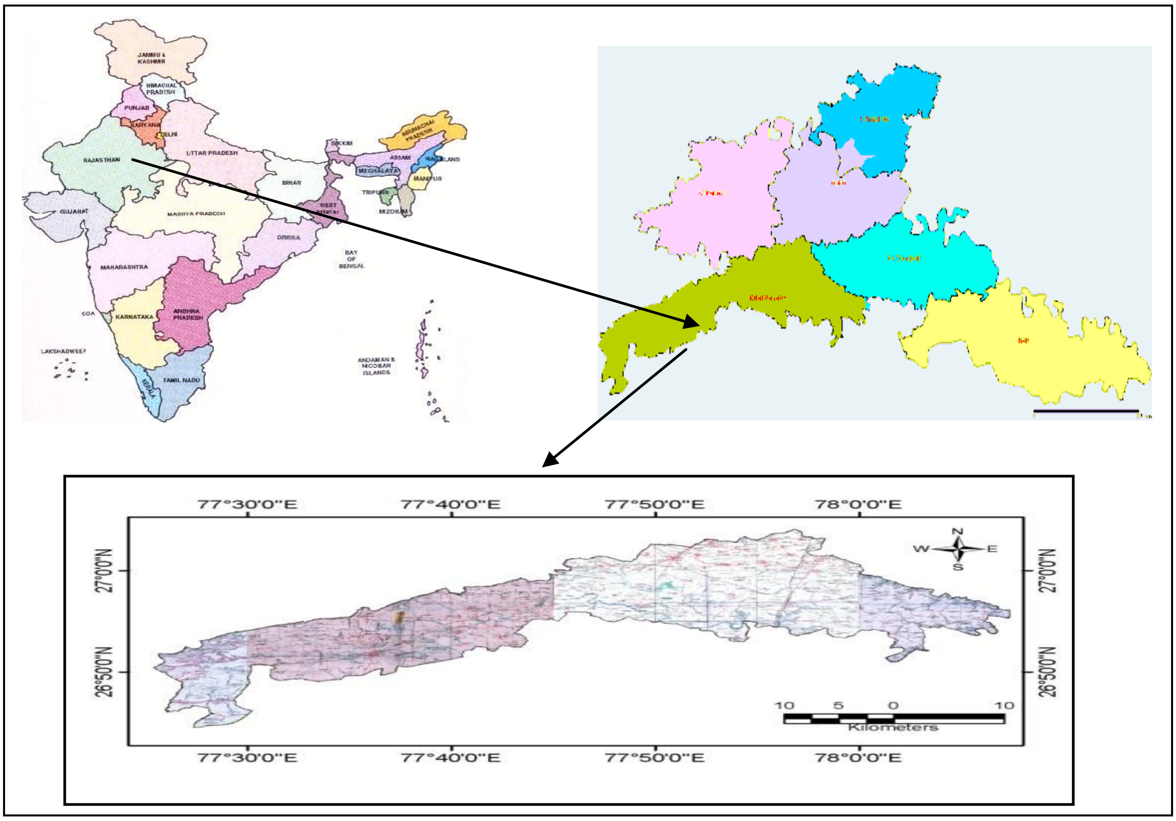

Fig.1 Location of the study area

Satellite and ancillary data

IRS-P6 LISS III satellite data (Fig. 2) of Feb, May and Oct, 2009 (path: 097, row: 052) were interpreted in consultant of the survey of India (SOI) toposheets No. 54E/16, 54F/5, 54F/6, 54F/9, 54F/13, 54I/4 and 54J/1 of 1:50,000 scale for extracting information, preparation of base maps and navigation purposes during ground truth. Two available reports (AIS&LUS, 2000 and AIS&LUS, 2009) pertaining to the area have also been used.

Methodology

The methodology followed in present study can be classified into four main steps (Fig. 3).

(1) Extraction of agricultural land

(i) Geometric and radiometric corrections

Using about 10 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.4.7), satellite image was geometrically corrected. The root mean square error (RMSE) was <0.5. Radiometric normalization was done based on Pseudo-invariant features (PIFs) in the images. The formula elaborated by Schott et al. (1988) was used in radiometric normalization and the error was <1 digital number (DN).

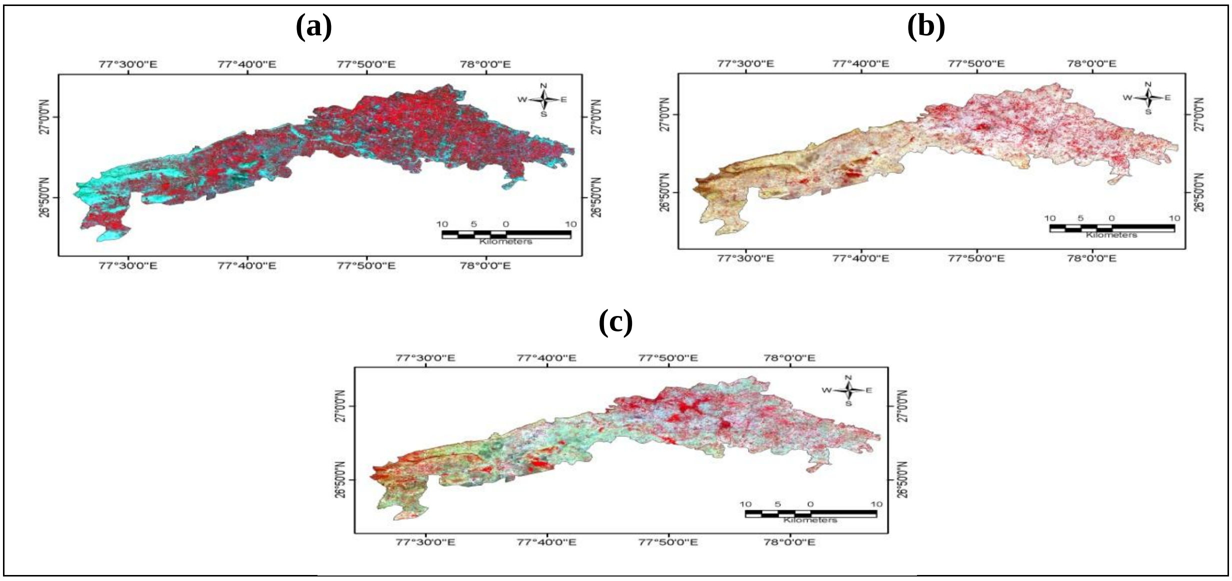

Fig. 2 FCC images of the study area: (a) February, (b) May, (c) October, 2009.

(ii) Extraction of the study area and agricultural land

The study area was extracted from the whole image through on screen digitization of the area of interest (AOI) and masking out using subset module of ENVI software (ver.4.7). The Normalized difference vegetation index (NDVI), being a potential indicator for crop growth and vigor was used for identifying the agricultural area. Incorporated (NDVI) with decision tree classifier (DTC), agricultural land (Fig. 4) successfully delineated and used for further analysis.

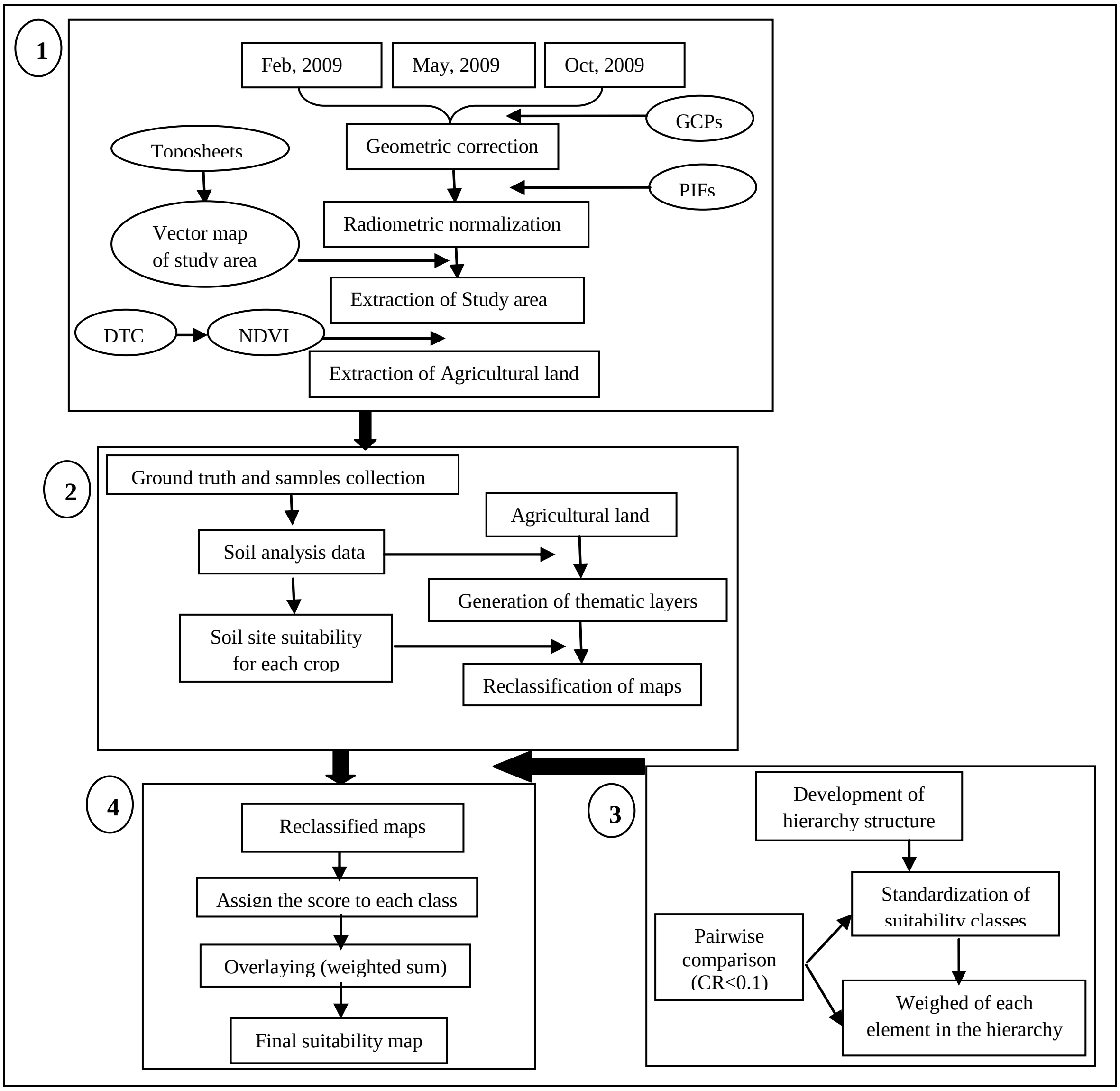

Fig. 3 Flowchart of the methodology followed in the study: (1) Extraction of agricultural land, (2) Ground truth and samples collection, (3) Applying MCE, (4) Integration MCE with GIS.

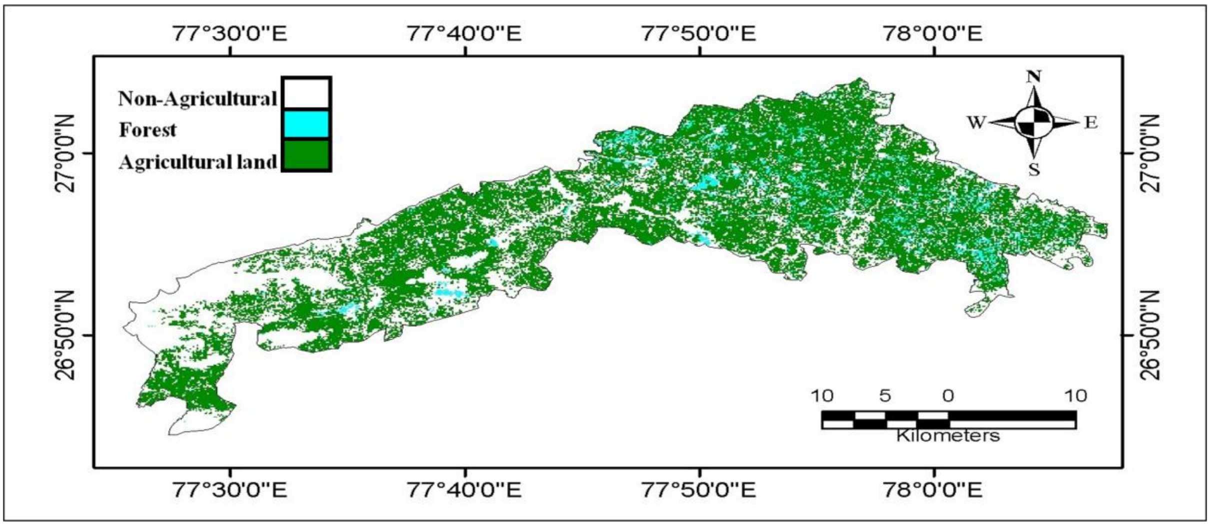

Fig.4 Agricultural land in the study area

(2) Ground truth data and samples collection and analysis

(i) Selection of profiles

Based on the variations in the image characteristics of soils of study area, representative soil samples were collected from agricultural land. Horizon wise samples were collected from each profiles and analyzed for physical and chemical characteristics using the standard analytical methods as described below.

(ii) Analysis for Soil chemical and physical properties

Particle size analysis was determined by international pipette method described by Black (1965). The moisture retention capacity of the soils at 1/3 and 15 bars was determined by pressure plate apparatus (Richard, 1965). The plant available water capacity (PAWC) was calculated following the formula given by Gardner *et al.* (1984). 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 (ECe) was determined using Elico conductivity bridge (CM 82T) following the procedure given by Jackson (1973). Soil reaction was determined in 1:2 suspension using standard pH meter (Jackson, 1973). The method described by (Bower et al., 1952) was used for 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 Kjeldahl distillation method (Subbian and Asija, 1956). The available Phosphorus was estimated by ascorbic acid method described by

Watanabe and Olsen (1965) and the concentration was quantified using spectrophotometer. Available Potassium was extracted by 1 N ammonium acetate solution at pH 7 as described by Jackson (1973) and determined by flamephotometer. DTPA- extractable micronutrients Fe, Mn, Zn and Cu were extracted from the soil samples by 0.005M DTPA at pH 7.3 according to Lindsay and Norvell (1978) and the concentration of the micronutrients was estimated by atomic absorption spectrophotometer (AAS).

(iii) Generation of thematic maps

Thematic maps were generated for each of the soil physical and chemical parameters using IDW interpolation provided in Arc GIS 9.3 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.

(3) 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:

(i) Generation a hierarchy structure

Malczewski (1999) stated that the relationship between the objectives and their attributes has a hierarchy structure. At highest level one can distinguish the objectives and at lower, the attributes can be decomposed. Fig. 5 shows the hierarchical structure used in the study.

(ii) 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 were applied using a scale with values from 9 to 1/9 introduced by Saaty, (1980). A rating of 9 indicates that in relation to 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 pair-wise comparison matrix

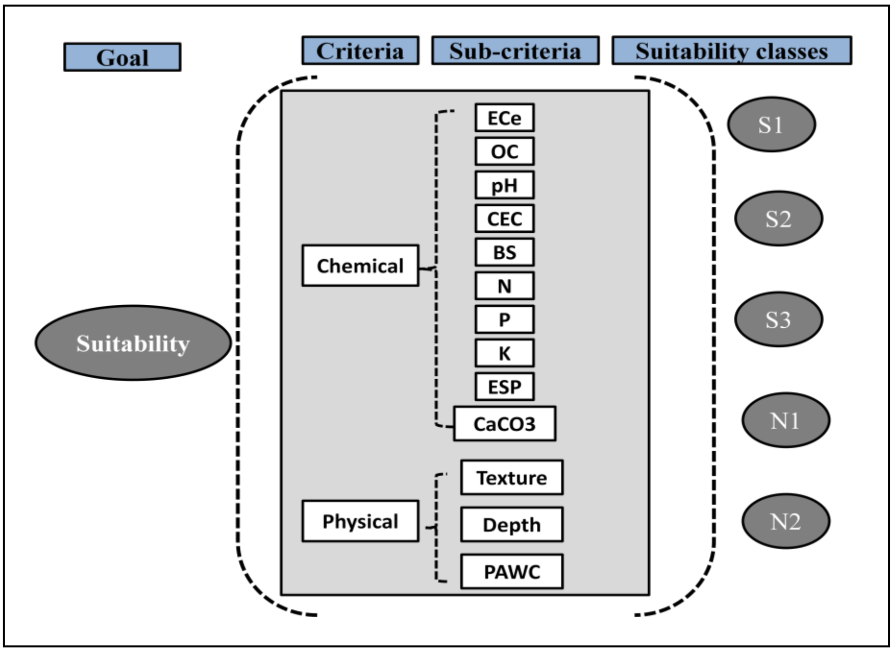

Fig. 5 Hierarchical organization for the criteria considered in the study

Table 1. Weighed the chemical criteria for barley

	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								∑=1

In 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 actually 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 ECe is 9, the rating of ECe relative to pH will be 1/9).

(iii) Rating the suitability classes of sub criteria

In land suitability analysis, a map represents each evaluation criteria 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). These classes have to be rated, how important is the class S1 with respect to a particular sub criterion to contribute for 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 as acceptable

$$CI = (\lambda - n) / (n - 1) \text{ .... } (1)$$
$$CR = CI / RI \text{ .... } (2)$$

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

Table 2. Rating of suitability classes for barley

	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						

(4) Integration with GIS

Once the standardized thematic layers and their weights or weightages were obtained for each crop, the weighted sum overlay within Arc GIS 9 was applied to produce the crop suitability map. Two multi crops suitability maps for *rabi* and *kharif* crops were generated using the same procedure.

Result & discussion:

(1) Spatial variability of soil properties

Land suitability evaluation, on basis of soil conditions requires criterion mostly from the soil attributes. Table 3 represents the main soil parameters used for generation of the thematic map layers which used in MCDM process for generating the final suitability map for each crop. The important soil parameters are discussed here under.

(i) 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 phyto- toxicity of elements for crops subsequently the soil suitability for specific crop. All the studied pedons were slightly to strongly alkaline and the soil pH values ranged between 7.77 and 8.96 with an average of 8.50 in the surface layer (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 limitations that deterred crop growing in the study area. Fig. shows the spatial variability of pH. Fig. 6 shows the spatial variability of pH throughout agricultural land.

Table. 3 Soil properties of the surface samples (0-30cm) in the study area

Pedon No.	pH (1:2)	ECe (dSm^{-1})	OC %	N	P_2O_5	K_2O	$CaCO_3$ %	ESP %	BS %	CEC	Soil texture
				($kg\ ha^{-1}$)							
P1	7.77	7.52	0.46	292.28	33.03	293.44	0.00	17.57	73.81	21.77	l
P2	8.19	7.60	0.37	271.58	29.24	244.16	0.00	16.57	69.91	19.48	l
P3	8.96	4.41	0.50	287.51	20.33	298.37	0.00	36.01	80.86	21.71	sil
P4	8.17	3.53	0.20	162.57	37.51	218.62	0.00	5.52	59.55	18.16	sl
P5	8.35	2.02	0.16	134.60	24.05	448.00	12.24	2.08	73.36	21.12	l
P6	8.67	1.52	0.31	239.97	7.00	177.86	0.00	3.97	51.68	22.30	l
P7	8.74	1.36	0.35	228.30	46.16	315.84	0.00	3.74	52.01	23.99	sil
P8	8.75	2.36	0.21	176.37	70.67	162.18	0.00	8.04	38.03	21.76	sl
P9	8.89	1.52	0.23	219.52	52.63	297.92	0.12	5.33	52.14	20.61	scl

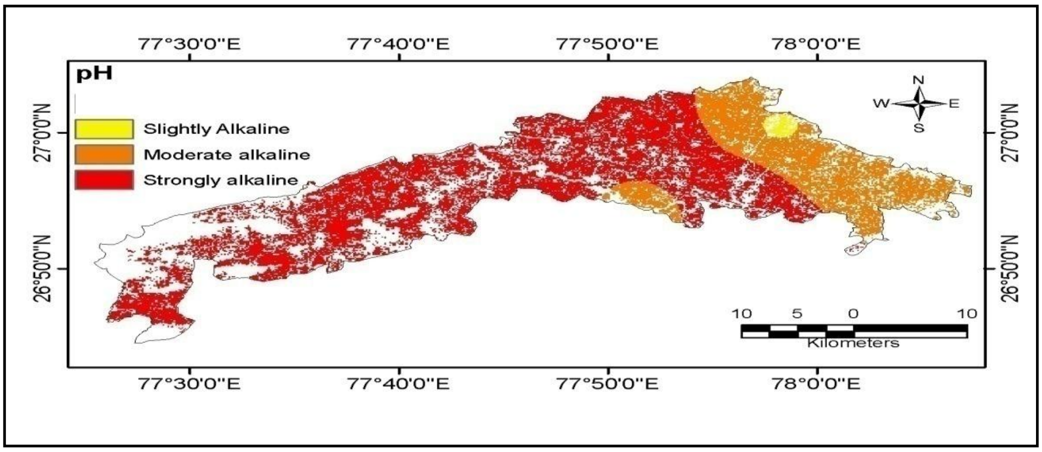

Fig. 6 Spatial variability of pH

(ii)Electrical conductivity (ECe)

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 ECe is given in Fig. 7. Data in Table 3 suggesting that the soils are slightly to strongly saline as the ECe values ranged between 1.36 and 7.6 dS m^{-1} with an average of 3.54 dS m^{-1}.

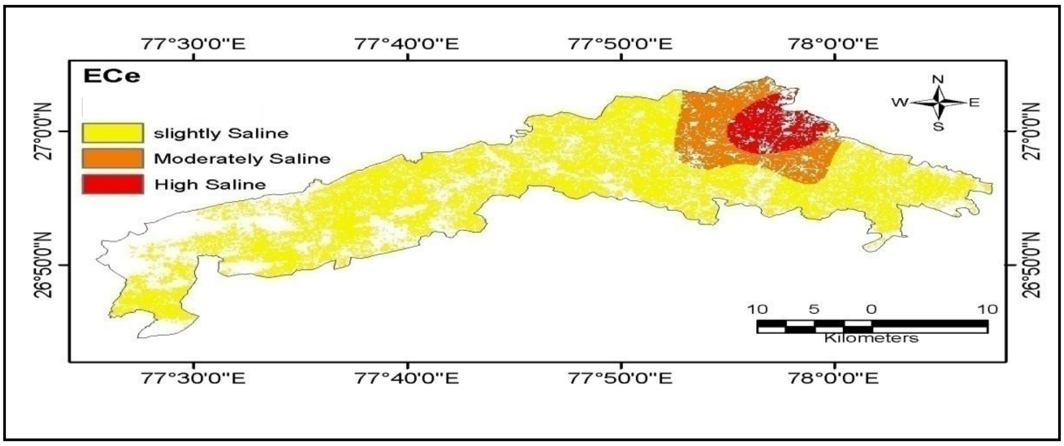

Fig. 7 Spatial variability of ECe

(iii) Organic carbon

Soil organic carbon (O.C) indicates the organic matter (O.M) content in the soil which has many benefits such as reservoir of plant nutrients especially N, P and S, also it is important for maintaining micronutrient cations in a available form and complexing Al in less phyto toxic form. In addition, it has a high water holding capacity hence minimizing the effects of moisture stress. The paramount character of O.M is high negative charges on its surface contributing to cation exchange capacity (CEC) which retains nutrients cations. Generally, the OC content of all pedons were low to medium and ranged from 0.16 to 0.5 % with an average of 0.31% in surface layers (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 texture classes is given in Fig. 8.

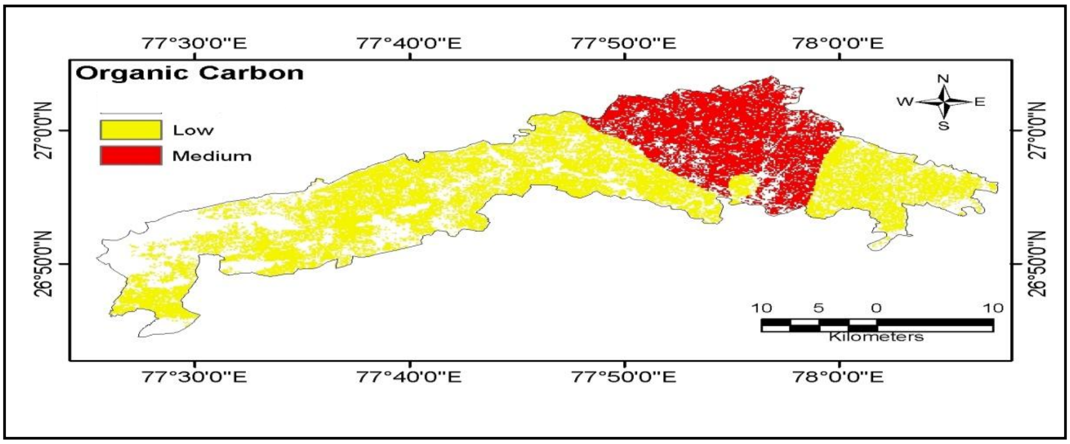

Fig. 8 Spatial variability of soil organic carbon.

(iv) Available nitrogen (N)

The available N values varied from 134.60 to 292.28 kg ha^{-1} with a mean value of 223.63 kg ha^{-1} suggesting that the soils having medium 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 Fig. 9.

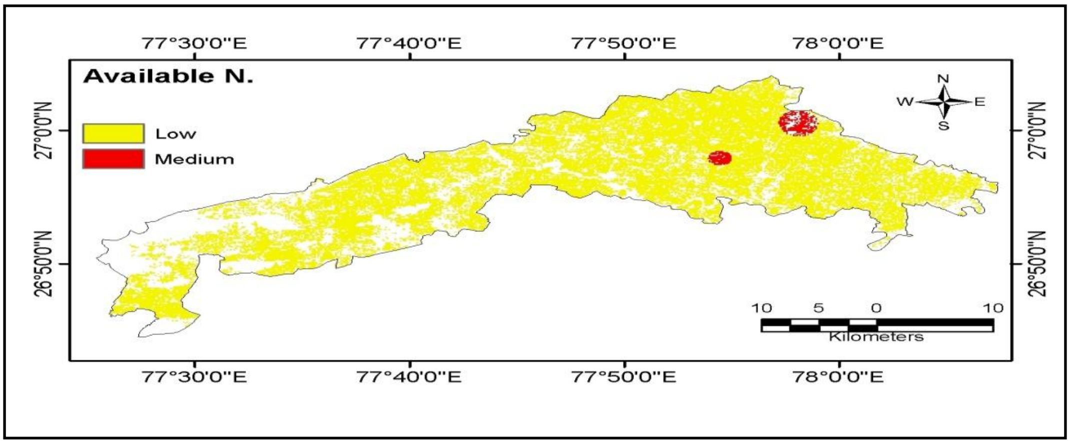

Fig. 9 Spatial variability of available N.

(v) Available phosphorus (P)

The spatial variability of available P is given in Fig. 10. The available phosphorus in the surface layers varied from minimum value of 7.00 to a maximum of 70.67 kg ha^{-1} with a mean value of 35.62 kg ha^{-1}. The high available P content might possibly be due to the confinement of crop cultivation to the rhizospher and supplementing of the depleted phosphorus through external sources i.e. fertilizers (Sharma *et al*., 2008).

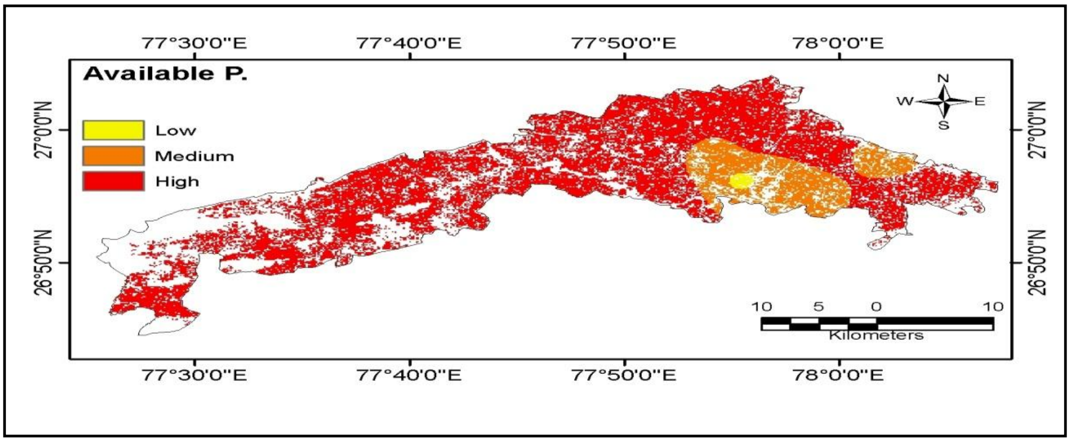

Fig. 10 Spatial variability of available P.

(vi)Available potassium (K)

Available K varied from 162.18 to 448.00 kg ha-1 with an average value of 272.93 kg ha-1. This suggests that these pedons contain enough amount of available potassium and may be attributed to the prevalence of potassium-rich minerals like illite and feldspars (Sharma *et al.*, 2008). Fig. 11 shows the spatial variability of available K.

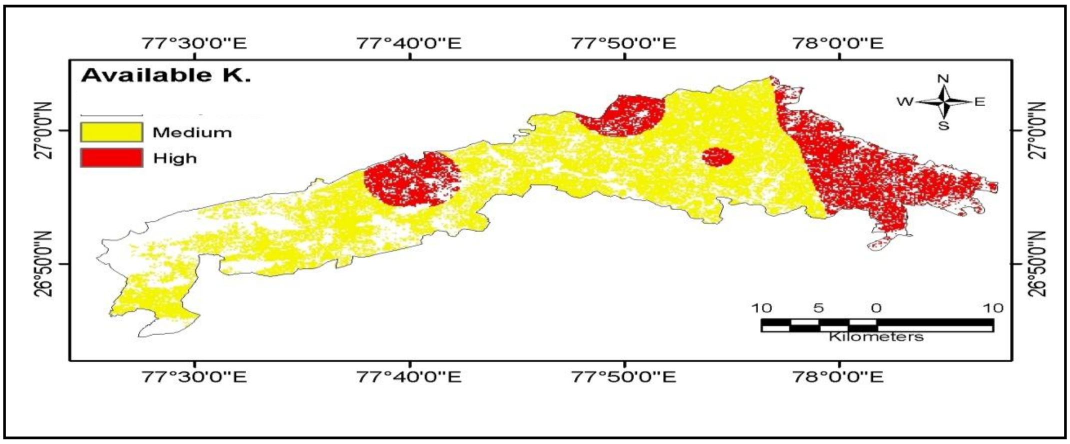

Fig. 11 Spatial variability of available K.

(vii) Exchangeable sodium percentage (ESP)

ESP varied between 2.08 and 36.01 % in the surface layers with an average of 10.98%. The highest values were found in profile P3. This factor is considered as one of important limitations in the area under study hence it render some areas under non suitable class. Fig. 12 shows the spatial variability of ESP.

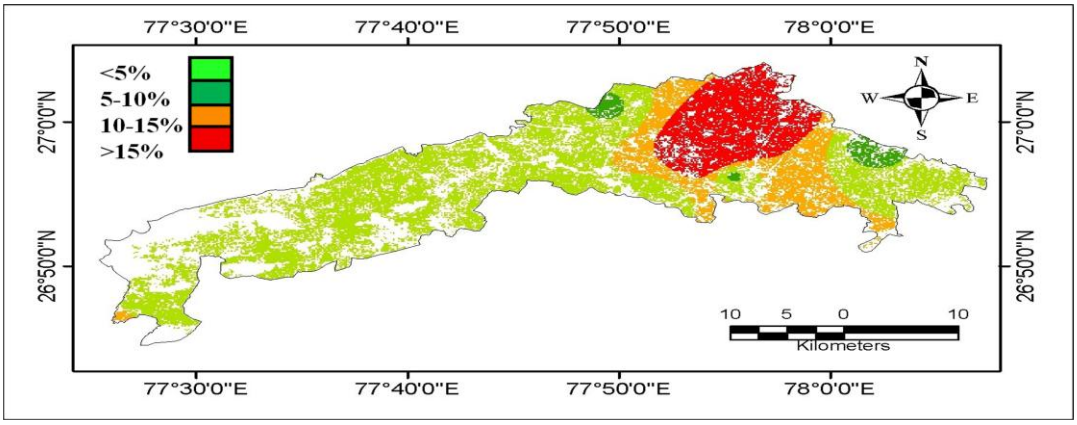

Fig. 12 Spatial variability of ESP

(viii) Base saturation (BS) and Cation exchange capacity (CEC)

The BS varied from 38.03 to 80.86 % with an average of 61.26 %. Whereas CEC varied from 18.16 to 23.99 cmol (p+) kg^{-1} with a mean value of 21.21 cmol (p+) kg^{-1}. These results indicates that the pedons are high to medium in CEC and BS as well. The spatial variability of BS and CEC are given in Fig. 13 &14.

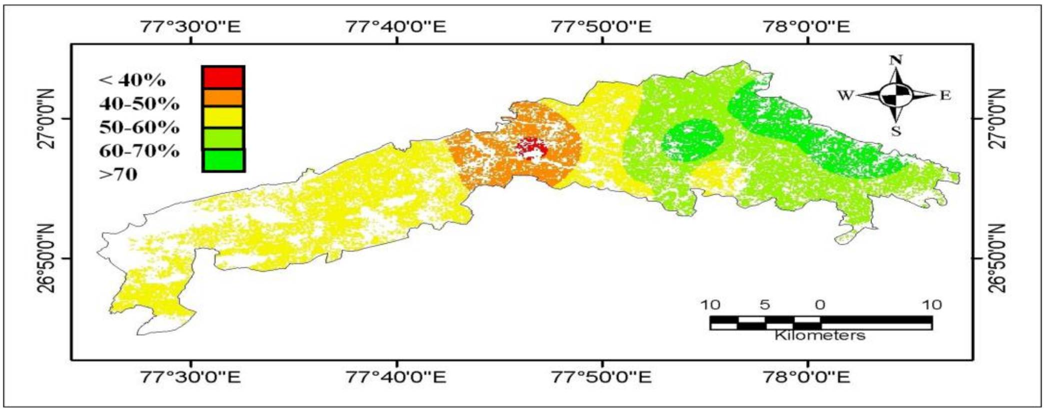

Fig. 13 Spatial variability of BS

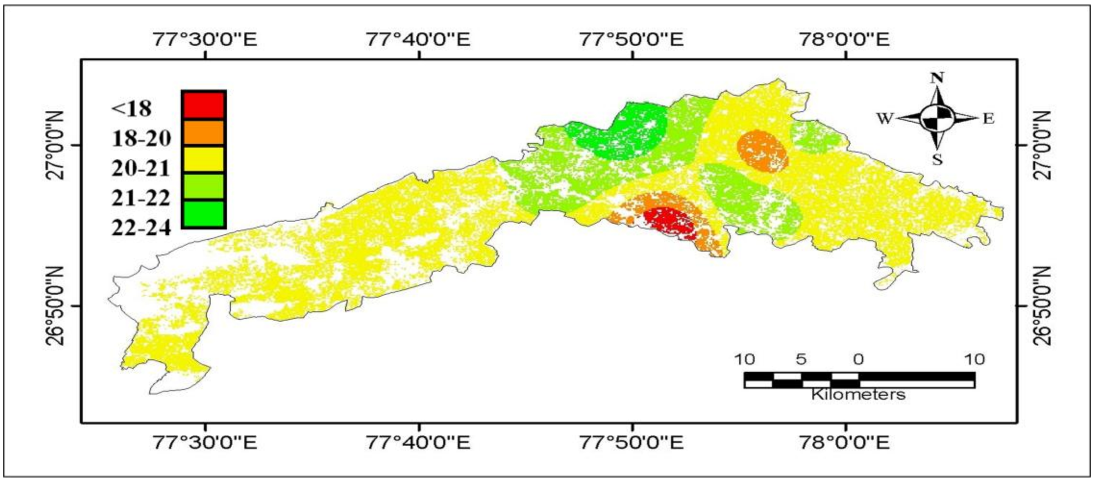

Fig. 14 Spatial variability of CEC

(ix)Soil texture

Texture is one of the important parameter of soil. Most of the physical characteristics of the soil depend upon texture class. Four texture classes occurred in the study area *viz*. loam (l), silty loam (sil), sandy loam (sl), sandy clay loam (scl). The spatial variability of soil texture classes is given in Fig. 15.

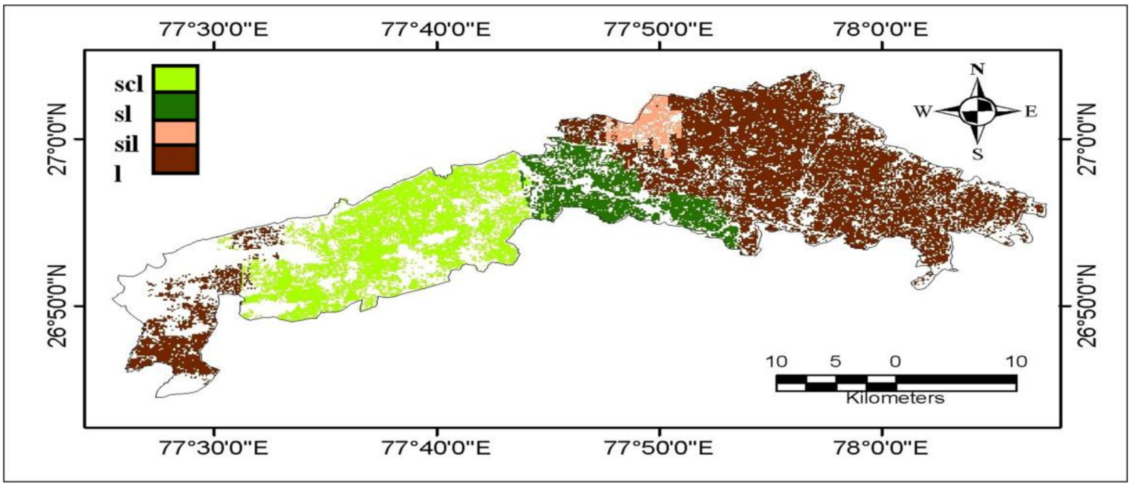

Fig. 15 Spatial variability of soil texture.

Soil suitability for different crops:

A total of 9 crops were evaluated for growing in the study area out of which 4 crops (mustard, sugarcane, wheat and barley) belong to *rabi* season whereas 5 are *kharif* crops (pearl millet, maize, cotton, rice and sorghum). Also, an attempt was made to generate a multi crops suitability map for *rabi* and *kharif* season. The data in Table 4 represent the area under different suitability classes and the results are discussed below.

(1)Rabi crops

(i) Mustard

Suitability analysis indicated that about 81.29% of agricultural area is suitable and out of which 10.83%, 54.75% and 15.17 % are highly (S1), moderately (S2) and marginally suitable (S3). The remaining area (18.71%) is having severe limitations that preclude the growing of Mustard. High ESP, pH and low organic carbon are the major limitations of this area which can be improved by specific management (Fig. 16)

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

Class	Mustard		Sugarcane		Wheat		Barley	
	ha	%	ha	%	ha	%	ha	%
N2	0	0	0	0	4571.161	9.64	219.9582	0.46
N1	8871.404	18.71	12858.3	27.11	10930.1	23.05	15898.18	33.52
S3	7449.069	15.71	5323.649	11.23	16807.78	35.44	6038.1	12.73
S2	25967.55	54.75	3117.452	6.57	7549.692	15.92	9830.31	20.73
S1	5138.601	10.83	26127.06	55.09	7567.884	15.95	15440.07	32.56
Total	47426.62	100	47426.62	100	47426.62	100	47426.62	100

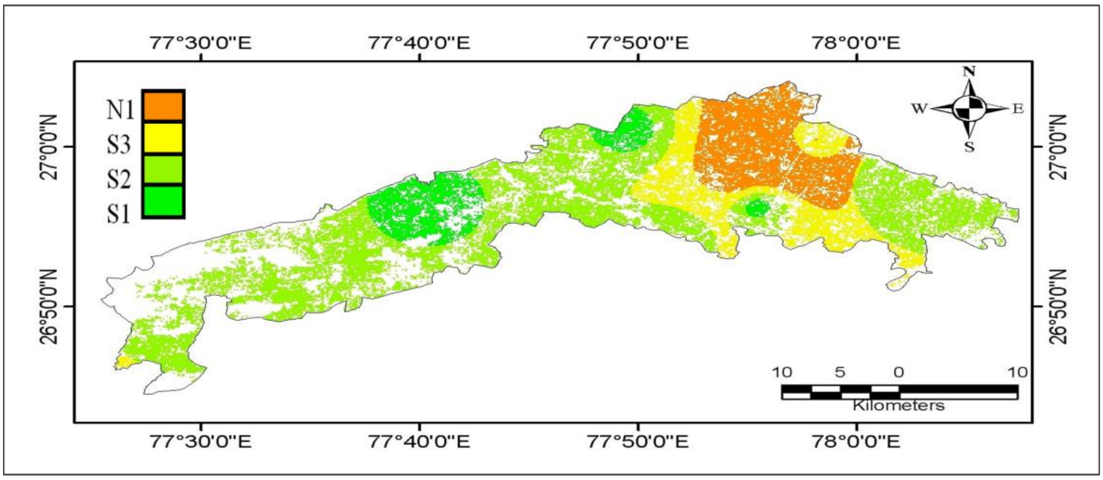

Fig. 16 Suitability map of mustard

(ii) Sugarcane

Almost of the area (55.09%) is highly suitable (S1) for sugarcane cropping (Fig. 17) and about 6.57% and 11.23% of the area are fall under S2 and S3 suitability classes. High pH and ESP are the major limitations which may be deterred farmers from cultivating this crop in about 27 % that belongs to N1 suitability class.

(iii)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 Fig. 18 clearly indicated that about 23.05% and 9.64% of area are placed under N1 and N2 classes respectively. Approximately, an equal area falls under S1 and S2 classes whereas double of this area falls under S3 suitability class.

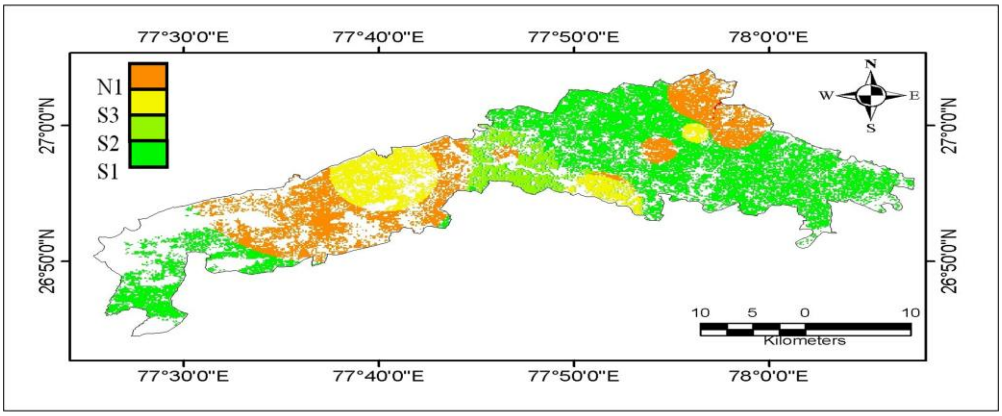

Fig. 17 Suitability map of sugarcane

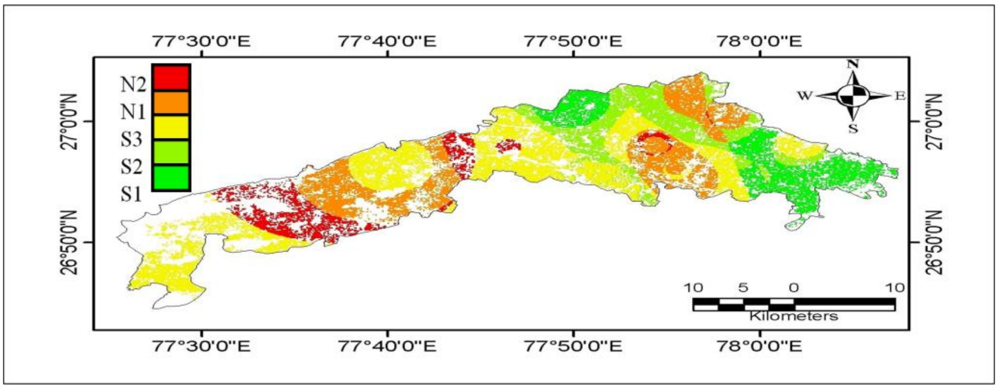

Fig. 18 Suitability map of wheat

(v)Barley

Although barley is more tolerant of soil salinity than other crops, about 33.52% of area is not suitable (Fig. 19). This may be due to the sandy loam and sandy clay loam texture that occur in area in addition to the low organic carbon and high ESP. Suitability analysis indicated that about 66.02% of agricultural area is suitable and out of which 32.56, 20.73% and 12.73 % are highly (S1), moderately (S2) and marginally suitable (S3).

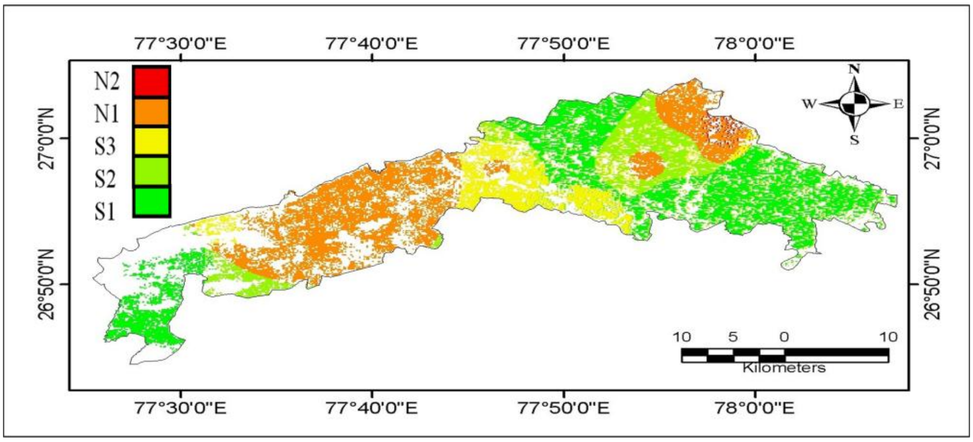

Fig. 19 Suitability map of barley

(vi)Multi crops suitability map

The results in Table 5 revealed that about 54.96% of area is suitable for growing the four *rabi* crops with the order of sugarcane> barley> mustard> wheat whereas 5.71% is not suitable for these crops (Fig. 20) due to high ESP and pH and can be improved by specific management.

Table 5. Percent of suitable area for *rabi* crops growing

Crop	%	Crop	%
Not Suitable	5.71	**Mustard>Barley**	0.92
Wheat	1.25	**Mustard>Sugarcane**	2.27
Mustard	18.60	**Sugarcane>Barley>Wheat**	10.38
Wheat>Barley	0.36	**Sugarcane>Barley>Mustard**	4.52
Sugarcane>Barley	1.01	**Sugarcane>Barley>Mustard>Wheat**	54.96

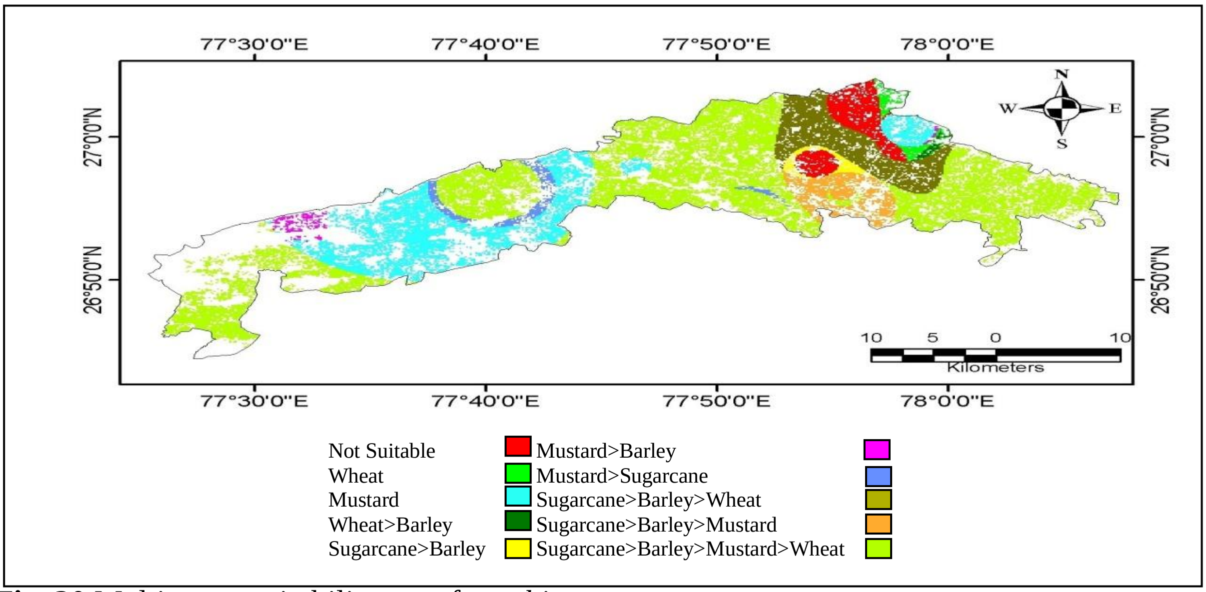

Fig. 20 Multi crops suitability map for *rabi* crops

(2)Kharif crops

(i) Pearl millet

Pearl millet is extensively cultivated in poor fertile soils, largely grown for home and local consumption. About 60.04% of (Table. 6) area is moderately suitable (S2) whereas 11.26% and 13.92% of area are highly and marginally suitable respectively. High ESP, pH and ECe are the major limitations which exclude about 14.78% of area from cultivation (Fig. 21)

(ii) Maize

Around 50.28% of area is marginally suitable for maize cropping while 24.34% and 6.34% are highly and moderately suitable respectively. Approximately, equal area falls under N1 and N2 classes.The major limitations are low organic carbon, potassium, nitrogen and high ESP and pH.

Table 6. Area under different categories of suitability for *kharif* crops

Class	Pearl millet		Maize		Cotton		Rice		Sorghum	
	ha	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**
N2	1933.317	4.08	4443.817	9.37	974.1684	2.05	264.7313	0.56	785.8746	1.66
N1	5073.922	10.70	4587.699	9.67	10955.67	23.10	11907.95	25.10	16028.19	33.80
S3	6602.053	13.92	23844.79	50.28	10259.37	21.63	4076.863	8.60	3038.826	6.40
S2	28473.83	60.04	3006.646	6.34	18290.88	38.57	23026.66	48.55	11130.18	23.47
S1	5343.495	11.26	11543.67	24.34	6946.532	14.65	8150.416	17.19	16443.55	34.67
Total	47426.62	100	47426.62	100	47426.62	100	47426.62	100	47426.62	100

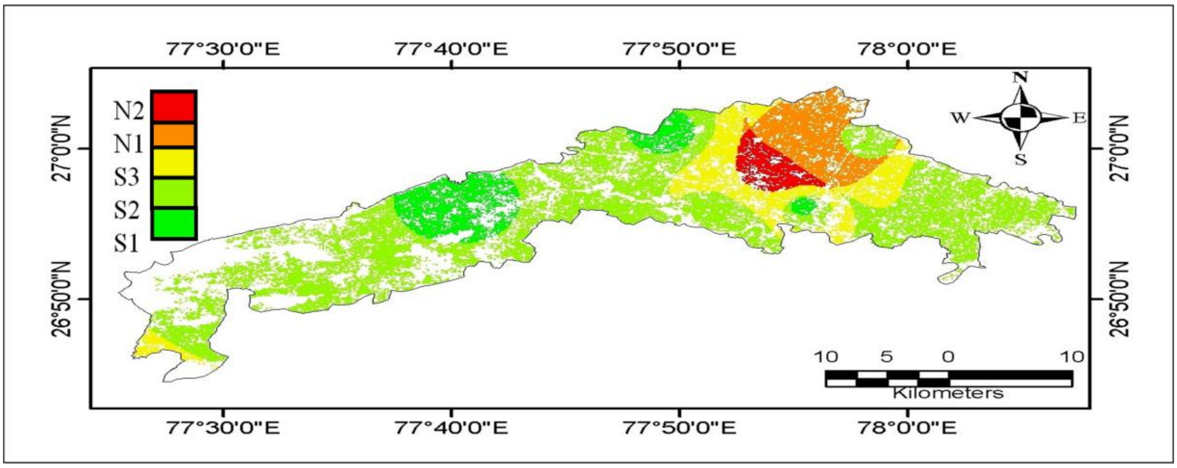

Fig. 21 Suitability map of pearl millet

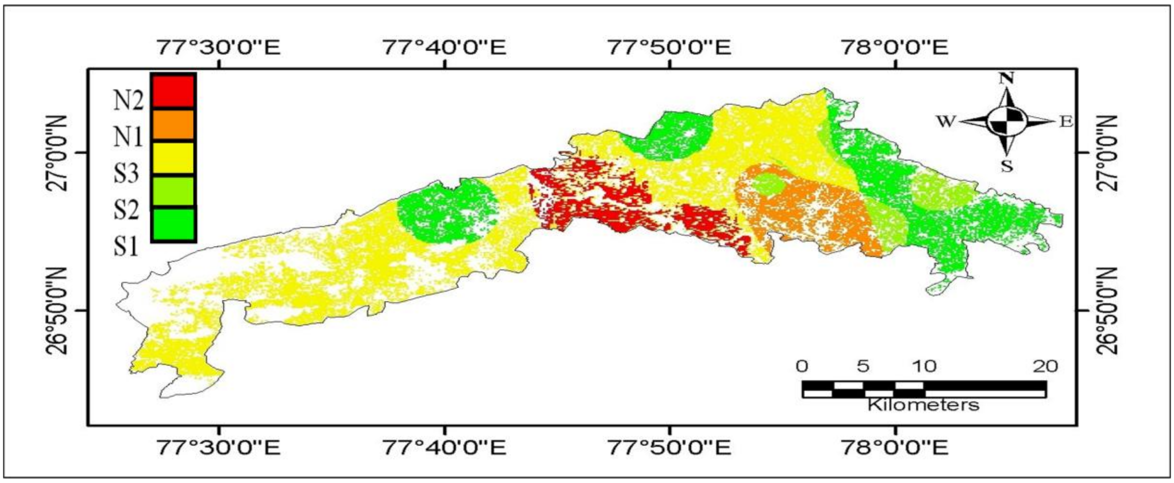

Fig. 22 Suitability map of maize

(iii) Cotton

The major limitations which may be precluded cotton cultivation are low organic carbon, low available nitrogen, low available potassium, low CEC and low base saturation. High pH and high ESP are also other limitations. About 74.85% of area is suitable out of which 14.65%, 38.57% and 21.63% are highly, moderately and marginally suitable. Only 23.10% and 2.05% belong to N1 and N2 suitability classes (Fig. 23)

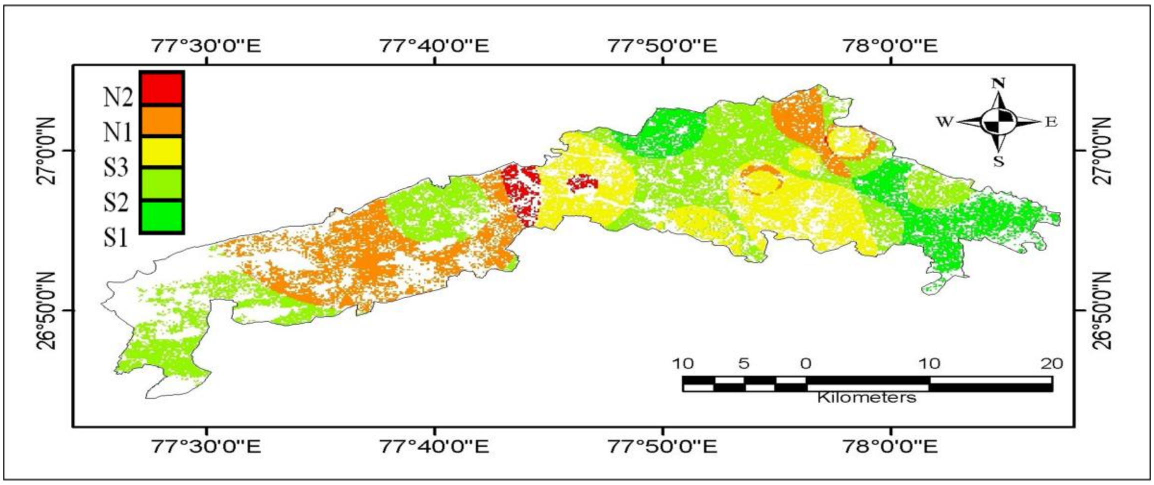

Fig. 23 Suitability map of cotton

(v) Rice

More of area (48.55%) is moderately suitable (S2) for growing rice and about 25.66% is not suitable. The low fertility of some areas especially organic carbon and subsequently available nitrogen and also available potassium are the paramount limitations. In other areas, high ESP and pH are considered more effective (Fig. 24).

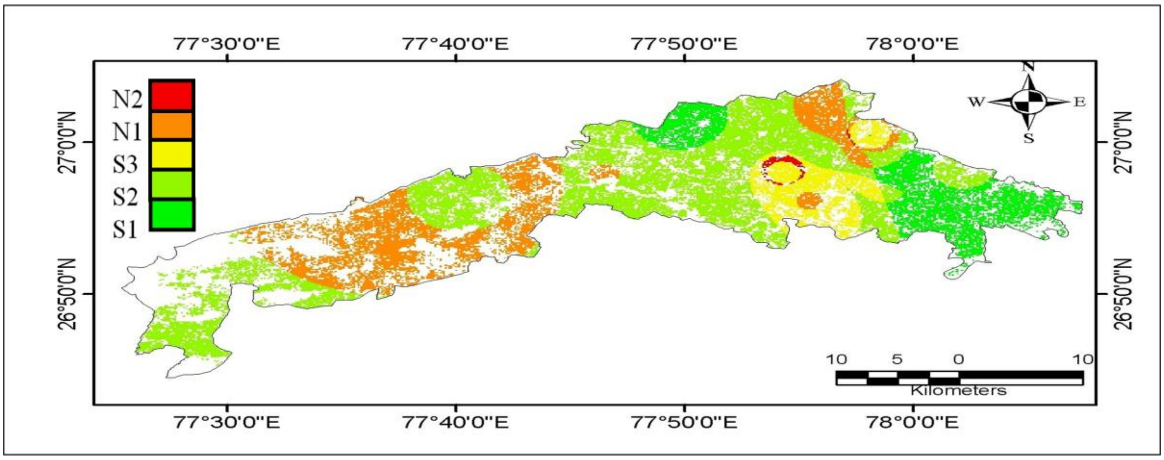

Fig. 24 Suitability map of cotton

(vi) Sorghum

The major limitations encounters 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 limited factors in other areas. The data in Table (6) clearly indicated that about 33.80% and 1.66% of area are placed under N1 and N2 classes respectively. About 64.54% is suitable for growing sorghum and out of which 34.67%, 23.47% and 6.40% are highly, moderately and marginally suitable (Fig. 25).

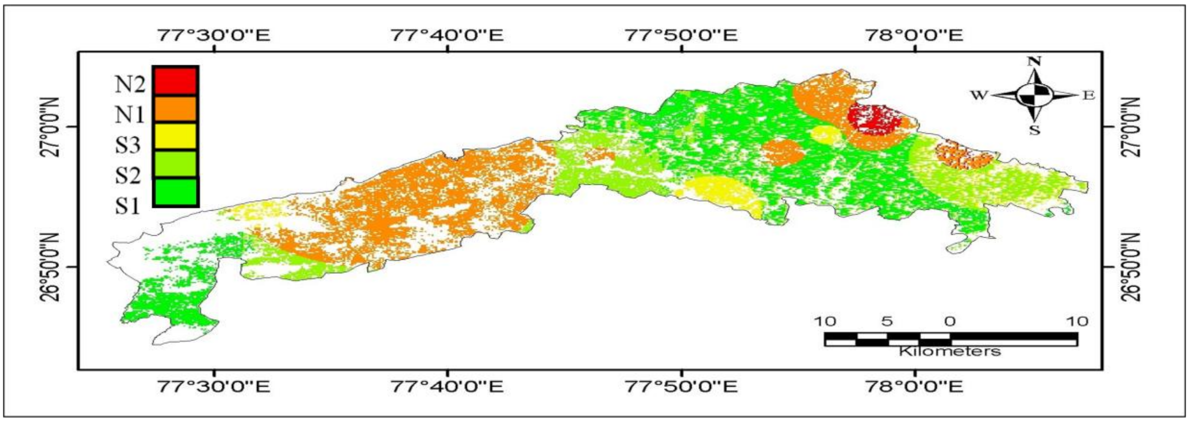

Fig. 25 Suitability map of sorghum

(iv)Multi crops suitability map

From data presented in Table 6, only 0.55% of area is not suitable for growing kharif crops and may be due to high ESP. About 39.33% of area is suitable for cropping kharif crops with the order of pearl millet/rice>cotton>sorghum>maize (Fig. 26).

Table 7. Percent of suitable area for *kharif* crops growing

Crop	%	Crop	%
Not suitable	0.55	**Cotton>Sorghum>Pearl millet**	0.54
Maize	4.27	**Pearl millet>Sorghum/Maize**	0.83
Pearl millet	0.93	**Sorghum>Rice>Cotton>Maize**	6.52
Pearl millet>Maize	18.58	**Cotton/Rice>Sorghum/Pearl millet**	15.57
Sorghum>Cotton>Rice	1.45	**Pearl millet/Maize>Cotton/Rice**	9.44
Maize>Rice/Cotton	1.99	**Pearl millet/Rice>Cotton>>Sorghum>Maize**	39.33

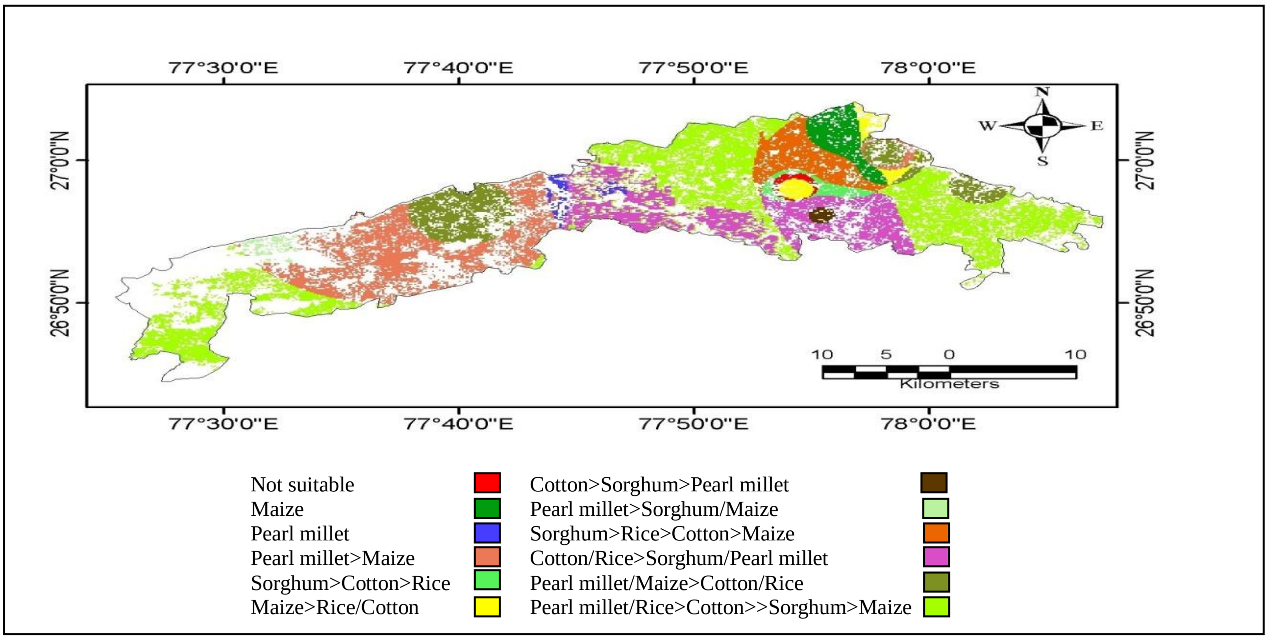

Fig. 26 Multi crops suitability map for *kharif* crop.

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 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, selection of more number of factors likes soil, climate, irrigation facilities, 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.

Acknowledgments

The authors are extremely thankful to Dr. S. N. Das, Chief Soil Survey Officer, All India Soil and Land Use Survey (AIS & LUS), IARI Building, New Delhi for his support especially for acquiring the remote sensing data. Secondly but not the least, the authors are highly grateful to Dr. S. K. Dubey , Head, Central Soil and Water Conservation Research and Training Institute (CSWCRTI), Research Center, Agra, Uttar Pradesh for providing facilities during soil survey and samples collection in the study area. Sincere thanks are also due to Dr. A.K. Barman, Soil Survey Officer, Soil and Land Use Survey of India (SLUSI), Regional Center, Noida, Uttar Pradesh for constant encouragement, inspiration and timely guidance during the course of investigation.

References:

All India Soil and Land Use Survey Organization (AIS&LUS) (2000). Inventory of degraded lands of Agra district, U.P. using Remote Sensing techniques. IARI, New Delhi.

All India Soil and Land Use Survey Organization (AIS&LUS) (2009). Soil resources mapping of Agra district. IARI, New Delhi.

Baniya, Nabarath. (2008). Land suitability evaluation using GIS for vegetable crops in Kathmandu valley, Nepal. Ph.D. thesis submitted to Humboldt University of Berlin.

Belka, K.M. (2005). Multicriteria analysis and GIS application in the selection of sustainable motorway corridor. Master's thesis submitted to *linkopings universitet Institutionen for datavetenskap.*

Black, C.A. (1965). Methods of soil analysis. Part I. American Society of Agronomy, Madison, Wisconsin, USA.

Bower, C.A., Reitemeiyer, R.F. and Fireman, M. (1952). Exchangeable cation analysis of saline and alkaline soils. *Soil Sci.* **73**:251-261.

Carver, S.J., 1991. Integrating multi-criteria evaluation with geographical information systems. International Journal of Geographical Information System, **5:** 321-339.

FAO. (1976). A framework for land evaluation: *Soils Bulletin **32***, Food and Agriculture Organization of the United Nations, Rome, Italy.

Gardner, S.P., Shaw, R.J., Smith, G.D. and Coughlan, K.J. (1984). Plant available water capacity: concept, measurement and prediction. In: Properties and utilization of cracking clay soils. *J. Univ. Of New England, Armedale,* pp.164-175.

Jackson, M.L. (1973). Soil chemical analysis. Prentice Hall of India Pvt. Ltd, New Delhi.

Kanlaya, T., Songkot, D., Chalie, N. (2009). Integration of land evaluation and the analytical hierarchical process method for energy crops in Kanchanaburi, Thailand. Science Asia, **53**:170-177

Khoi, D.D. and Murayama, Y. (2010). Delineation of suitable cropland areas using a GIS based multi-criteria evaluation approach in the Tam Dao National Park Region, Vietnam. *Sustainability*, **2**:2024-2043.

Lindsay, W.L. and norvell, W.A. (1978). Development of a DTPA micronutrients soil test for zn, Fe, Mn and Cu. *Soil Sci. Soc. Am. Proc.*, **42**: 421-428.

Malczewski, J. (1999). GIS and multicriteria decision analysis. Wiley & Sons Inc., New York, USA.

Malczewski, J. (2006). GIS-based multicriteria analysis: a survey of the literature. *International Journal of Geographic Information Science*, **20**: 703–726.

Nayak, D.C., Sarkar, D. and Das, K. (2002). Forms and distribution of pedogenic iron, aluminium and manganese in som Benchmark soils of West Bengal. *J. of the Indian Soc. of Soil Sci.*, **50**:89-93.

Prasuna Rani, P.P., Pillai, R.N., Bhanu Prasad, V. and Subbaiah, G.V. (1992). Nutrient status of some red and associated soils of Nellore District under Somasila project in Andhra Ppedesh. *The Andhra Agricultural J*., **39**:1-5.

Richards, L.A. (1965). Physical condition of water in soil. In: C.A. Black (editor in chief). Methods of Soil Analysis, Part I, Am. Soc. Of Agronomy, Inc., Publishers, Madison, Wisconsin, USA.

Saaty, T.L. (1980). The analytic hierarchy process: McGraw Hill International., New York.

Schott, J.R., Salvanggio, C. and Volchok, W.J. (1988). Radiometric scene normalization using pseudoinvariant features. *Remote Sens. Environ*, **26**: 1:16.

Sehgal, J. (1999). Pedology: Concept and Applications. Kalyani publishers.Lodhiana, India.

Sharma, P.K., Sood, A., Setia, R.K., Tur, N.S., Mehra Deepak and Singh, H. (2008). Mapping of Micronutrients in Soils of Amritsar Dsitrict, Punjab – GIS approach. *J. of Indian Soc. Soil Sci.*, **56**:34-41.

Subbaiah, B.V. and Asija, G.L. (1965). A rapid procedure for determination of available nitrogen in soil. *Curr Sci*, **25**: 259-260.

Sys, I.C., Van Ranst, B. and Debaveye, J. (1991). Land evaluation. Part I. Principles in land evaluation and crop production calculations. International training center for post graduate soil scientists, University Ghent.

Watanabe, F.S. and Olsen, S.R. (1965). Test of ascorbic acid method for determining phosphorus in water and Na HCO_3extract from soils. *Soil Sci. Soc. Am. Proc*., **29**:677-678.

Williams, D.E. (1949). A rapide manometric method for determination of calcium carbonate in soil. *Soil Sci. Am. Proc*., **13**:127-129.