Land evaluation for major crops in the Indo-Gangetic Plains and black soil regions using fuzzy model

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Land evaluation is carried out to assess the suitability of land for a specific use. Land evaluation procedures focus increasingly on the use of quantitative procedures to enhance the qualitative interpretation of land resource surveys. Conventional Boolean retrieval of soil survey data and logical models for assessing land suitability, treat both spatial units and attribute value ranges as exactly specifiable quantities. They ignore the continuous nature of soil and landscape variation and uncertainties in measurement, which may result in the failure to correctly classify sites that just fail to match strictly defined requirements. The objective of this article is to apply fuzzy model to land suitability evaluation for major crops in the 15 benchmark sites of the Indo-Gangetic Plains (IGP) and 17 benchmark sites of the black soil regions (BSR). Minimum datasets of land characteristics considered relevant to rice and wheat in the IGP and cotton and soybean in the BSR were identified to enhance pragmatic value of land evaluation. The use of fuzzy model is intuitive, robust and helpful for land suitability evaluation and classification, especially in applications in which subtle differences in land characteristics are of a major interest, such as development of threshold values of land characteristics.

Keywords: Benchmark sites, fuzzy model, land evaluation, minimum datasets.

Introduction

THE impact of human interventions on natural systems is developing as a critical issue for the future sustainability of land. Increasing population pressure and increasing demands for services from a fixed land base are threatening its quality and natural regulating functions. Increase in agricultural production is obtained conventionally by expanding the area under cultivation and increasing the inputs. In the Indian context, however, the extension of gross cropped area is less likely; the increase in agricultural productivity has to come from the land already under cultivation. In such a setting, the quality of the cropped land becomes immensely significant. Land quality has been described as the capacity of land resource to produce economic goods, services and environmental safety. It is a composite parameter which is determined on the basis of various factors like soil, terrain, water, climate and biotic components. One needs to appreciate that efficiency of agricultural development policies as well as land-related environmental programmes, including those designed to address land-use planning issues, can be enhanced considerably if decisions are based on the analysis of land quality.

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It is in this context that the land quality indicators assume importance. These indicators refer to measurable land attributes that influence the capacity of the land to perform crop production or environmental function. The indicators need to be developed to expand knowledge and understanding of land management issues to enable decision makers guide sustainable land management.

The process of evaluating soil/land quality is undertaken through a number of approaches and 'land evaluation' has much to offer to the process. Land evaluation is the assessment of performance (suitability or otherwise) of land for defined uses[1]. Land suitability is defined in land evaluation as the fitness of a given land unit for a specified type of land use. It is carried out mostly on the basis of biophysical parameters rather than socio-economic conditions of an area[2]. Biophysical factors tend to remain stable, unlike socio-economic factors that are affected by social, economic and political settings. Thus, physical land suitability evaluation is a prerequisite for land-use planning and development[3]. It provides information on the constraints and opportunities for use of the land and, therefore, guides decisions on optimal utilization of land resources. In a more operational sense, suitability expresses how well the biophysical potentialities and limitations of the land unit match the requirements of the land use type[2].

The Indo-Gangetic Plains (IGP) and black soil regions (BSR) account for about 128 m ha area of the country and are the two major crop-producing regions which together address the issue food security of the country to a large extent. Therefore, primary food security concerns of the country are focused on improving and sustaining their productivity. No systematic land evaluation, however, had ever been undertaken for major crops in IGP and BSR. Various methods of land evaluation that are in vogue can be grouped under: (a) qualitative and (b) quantitative methods. Qualitative methods are useful tools in research for regionalization and diversification of agriculture; yet, they are incapable of simulating the impact of the small-scale temporal and spatial changes in climate, topography and soil.

Since land evaluation is intended to mainly optimize the productive function of the land, besides obtaining other important land information at the same time, quantitative methods are comparatively better in delivering the desired results. Looking for solution to the methodological shortcomings of the conventional land evaluation tools and for assessing suitability (or otherwise) of major crops in the IGP, namely rice and wheat, and in BSR, namely cotton and soybean, fuzzy modelling-based method was used.

In general terms, the conventional land evaluation systems follow a Boolean or rule-based approach adapted to the principle of maximum limiting factors. There is a growing concern regarding failure of this method to incorporate the inexact or fuzzy nature of much of the land resource data. In recent years, there has been marked interest in the use of fuzzy-set methodology in land evaluation, and it can be considered as a new phase in the quantification trend. The use of fuzzy modelling in land evaluation is of particular importance in those cases where the impact of one land characteristic, which has a value just outside a specified range, can be minimized. The rigid Boolean logic of land suitability, as determined by limiting land characteristics, is replaced by fuzzy membership functions. Individuals that exactly match strictly defined classes are assigned a membership value (MF) of 1. Individuals falling outside the defined class range are given a membership value ($0.0 < MF < 1.0$) depending on their degree of closeness to the defined class. Fuzzy-set methodology is a refinement of Boolean logic, which has only two possibilities of membership: full (MF value 1) or none (MF value 0). In fuzzy methodology, land characteristics, which are given in classes, are converted to a grade of membership, depending on the values of the characteristics. The use of strict Boolean algebra with a simple true/false logic in combination with a rigid and exact model is often inappropriate for land evaluation, because of the continuous nature of soil variation, the uncertainties associated with describing the phenomenon itself or in the measurements made on it, or because of inexactness in formulating queries. Land evaluation using the fuzzy-set methodology is, however, also subject to data and knowledge limitations in just the same way as other methodologies[4,5].

In evaluating land quality by this method, various parameters are assigned values which are then arranged into a single index to represent the quality of the land. The index so developed is a 'relative' measure of land quality and is used to compare different land units for their crop production performance.

Often land evaluation methods use a number of land characteristics that are neither mutually exclusive nor locally relevant. There arises a need of identifying a minimum dataset (MDS) of land characteristics to enable assessing land quality appropriately, effectively and meaningfully. In concept, the development of MDS involves selection of a small subset of attributes that will comprise locally relevant indicators and be exclusive.

Land quality is said to be changing; but, on the other hand, there is hardly any formal monitoring of what is changing in terms of direction and/or rate. Changes in soil quality can be assessed by measuring appropriate indicators and comparing them with desired values, i.e. the critical limits or threshold levels/values at different time intervals, for specific use in a selected agro-ecosystem. A critical limit or a threshold value is the specific (desirable) value of a land characteristic or range of values for a selected soil indicator that must be maintained for normal functioning of health of the soil ecosystem[6]. It is also that value (or a range of values) of the indicator required to ensure that a soil process or function is not restricted or adversely influenced. They can be related to a clear decline in land quality (status) or to a significant impact of degradation on land productivity or environmental functioning.

The definition and assessment of soil/land quality is problematic and it is even more difficult to set the lower or upper limits (the thresholds) for the various attributes of soil/land quality[7]. This is exactly why very limited information was available till almost the end of the 20th century on various thresholds developed for land characteristics. With the relatively recent development of new concepts of soil/land quality, based on its inherent functional capacity, the possibility of developing threshold values (i.e. the critical limits) of land characteristics are realized and consequently, this has generated threshold values for different land use systems and management practices in different agro-ecological settings. However, generalized evidence for thresholds of the MDS components in case of the major crops of the IGP (rice and wheat) and the BSR (cotton and soybean) is not available. An attempt is made to develop thresholds of land characteristics for the said crops in these two regions, to use the land characteristics in a practical way.

Materials and methods

Study area

The Indo-Gangetic Plains: The IGP ranks as one of the most extensive fluvial plains of the world. The deposit of this tract represents the most recent chapter of Earth's history in India. The IGP developed mainly from the alluvium of the Indus, Yamuna, Ganga, Ramganga, Ghagra, Rapti, Gandak, Bhagirathi, Silai, Damodar, Ajay and Kashi rivers. The IGP covers about 52.01 m ha and represents 29 agro-ecological sub-regions (AESRs)[8]. The nature and properties of the alluvium vary in texture from sandy to clayey, calcareous to non-calcareous and acidic to alkaline. Though the overall topographic situation remains fairly uniform with elevations of 150 m amsl in Bengal basin, and 300 m amsl in the Punjab plain, local geomorphic variations are significant[9]. A total of 15 benchmark (BM) spots were selected for the present study.

Black soil regions: Black soils and their intergrades are common in the semi-arid tropics (SAT) in India, although their presence has been reported in the humid and arid bioclimatic zones also[10,11]. These soils occur on varied parent materials, namely basalts and other basic rocks and under varied climatic conditions[11]. They have been reported in the different physiographic positions. The BSR covers about 76.4 m ha and represents 54 AESRs[8]. Seventeen BM spots under similar management conditions were selected for the present study.

Selection of soils

Soils were selected, one each from the 15 BM sites in major AESRs representing rice–wheat cropping system in the IGP (Figure 1) and from 17 BM sites in major AESRs representing rainfed cotton-based cropping system in BSR (Figure 2). Cotton and soybean are the two selected

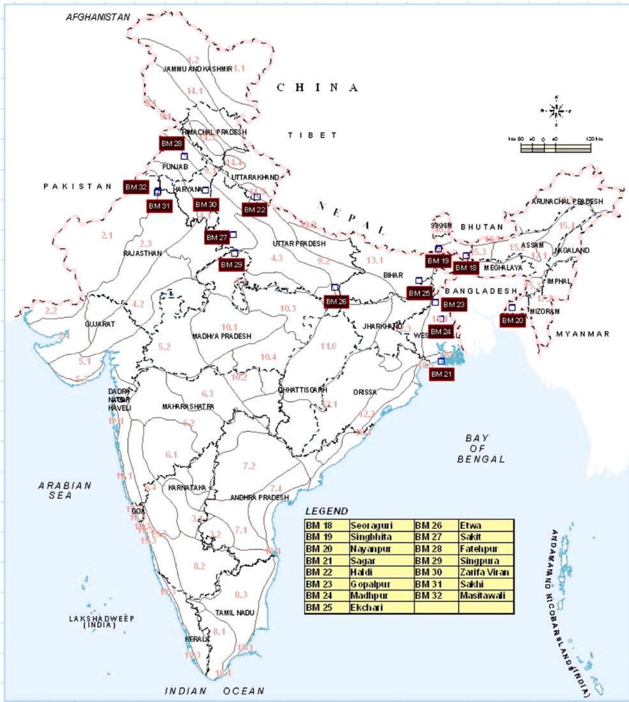

Figure 1. Location of benchmark spots in the Indo-Gangetic Plains.

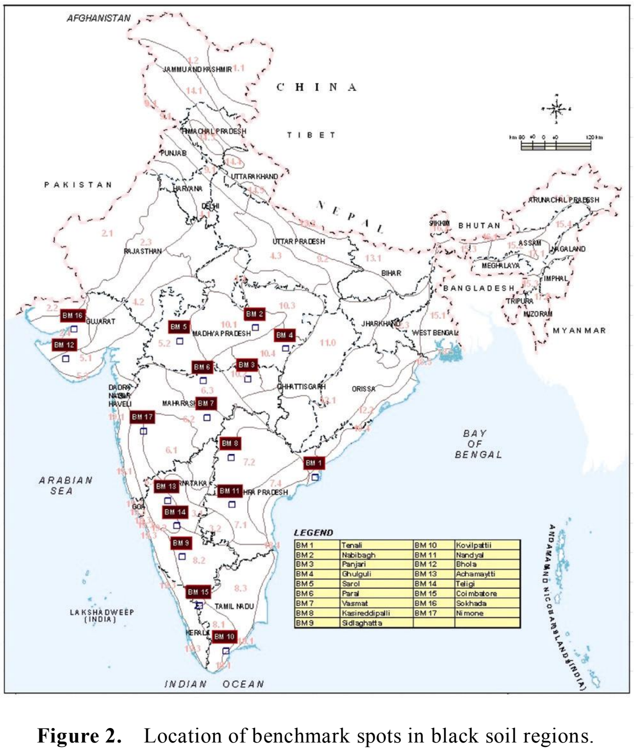

Figure 2. Location of benchmark spots in black soil regions.

Table 1. Minimum datasets (MDS) identified for land evaluation in the IGP

MDS component	Justification
Rice	
Coefficient of linear extensibility (COLE)	COLE gives an indication of reversible shrink–swell capacity of soil. High COLE values may cause root damage under dry condition
Rainfall	Rice is a water-loving crop. It requires 1400–1800 mm water. If this much rain occurs during cropping season with fairly good distribution, it will be sufficient for the crop.
Texture (% clay)	Clayey soils (vertic properties) are preferable as they can hold more water.
Slope	Levelled land having smooth surfaces is better suited for rice as it facilitates even distribution of water in the field.
Wheat	
Electrical conductivity	High salt concentration in soil reduces the availability of water to the plant due to high osmotic potential.
Bulk density	It influences the availability of water, nutrient and oxygen diffusion rate (ODR) to wheat crop and thus affects plant growth.
Minimum temperature at seedling stage	The yield potential of crop mainly depends on climate. About 50% of variation of crop is determined by climate. Temperature perceiving at seedling stage influences wheat growth a great deal. Required temperature for wheat (minimum 3–4°C – optimum 25°C, maximum – 30–32°C). Germination of seed may occur between 4°C and 37°C, optimal temperature being 12–25°C.
Exchangeable sodium percent	High sodium percentage leads to structural decline, e.g. dispersion of soil aggregates into individual soil particles leading to reduced water availability, low sHC, low permeability and reduced crop yield as a result of reduced availability of other nutrients (barring transplanted rice which is more tolerant to high sodium content).

Table 2. Minimum datasets identified for land evaluation in black soil regions

MDS component	Justification
Rainfed cotton	
ESP	High sodium percentage leads to structural decline, e.g. dispersion of soil aggregates into individual soil particles leading to reduced water availability, low sHC, low permeability and reduced crop yield as a result of reduced availability of other nutrients.
sHC	Saturated hydraulic conductivity is an important parameter which governs movement of water in the soils. Soils with high sHC allow movement of rainwater to the deeper layers which can be utilized by cotton roots.
Soybean	
Clay	Clay by virtue of its capacity to hold more water favours soybean cultivation.
ESP	High sodium percentage leads to structural decline, e.g. dispersion of soil aggregates into individual soil particles leading to reduced water availability, low sHC, low permeability and reduced crop yield as a result of reduced availability of other nutrients.
sHC	Saturated hydraulic conductivity is an important parameter which governs movement of water in the soils.

Table 3. Values of selected parameters of MDS for rice in IGP

Soil series	Rainfall (mm)	ESP	COLE	Clay (%)	Slope (%)
Mashitawali	221	12.74	0.03	8.8	2.0
Shakhi-2	263	6.87	0.02	7.6	0.5
Zarifaviran	705	6.00	0.06	21.7	0.5
Sakit	782	4.73	0.07	33.1	0.5
Singhpura	725	3.63	0.08	28.5	0.5
Fatepur	734	2.68	0.00	9.2	0.5
Itwa	1003	4.36	0.06	26.4	0.5
Gopalpur	1350	1.79	0.17	49.5	2.0
Ekchari	1105	2.59	0.10	32.4	2.5
Haldi	1700	3.03	0.04	17.1	0.5
Madhpur	1338	1.75	0.11	32.8	2.0
Singbhita	2627	2.33	0.00	24.3	0.5
Seoraguri	3261	2.85	0.00	20.1	0.5
Nayanpur	2178	1.70	0.06	27.0	0.5
Sagar HM	1783	12.15	0.09	40.8	0.5

Values are for 0–150 cm weighted means.

crops from the BSR and rice and wheat are the crops selected from IGP for land evaluation. Care was taken to ensure that all the selected soils are under similar management for comparability of land evaluation results.

Soil analysis

Saturated hydraulic conductivity (sHC) of the soils was estimated from clay content (%), pH and exchangeable Ca/Mg using a pedotransfer function[12]. Bulk density (BD) and electrical conductivity (ECe) were determined according to the Richards[13]. Coefficient of linear extensibility (COLE) was determined according to the method of Schafer and Singer[14]. Exchangeable sodium percentage (ESP) was determined following the standard procedures[13].

Land evaluation using fuzzy modelling-based approach

This method consists of three steps, viz. generation of membership values for the land characteristics, determination of weights for the membership values, and combination of weighted membership values to produce a joint membership value or composite land suitability index. Membership values were generated for the minimum datasets of land characteristics for soils of the IGP for rice and wheat and also for soils of the BSR for cotton and soybean using the following relation:

$$\mu Ai(z) = \frac{1}{1 + a_i (z - c)^2} \quad \text{for } 0 \le z \le £, \tag{1}$$

where A is the land characteristic set, a the dispersion index that determines the shape of the function, c (called the ideal value or standard index) the value of the property z at the centre of the set and £ is the maximum value that z can take. The composite land suitability index (I) at each sampling point was computed using the convex combination rule, which is a linear weighted combination of membership values of each land characteristic Ai

$$i = \sum_{i=1}^{n} w_i \mu Ai, \tag{2}$$

where w_i are the weights of the memberships value μAi.

Equation (2) shows that the choice of weights w_i is crucial in the determination of the overall land suitability index. Davidson *et al.*[15] suggest that this choice should be based on data and knowledge of the relative importance of differentiating land characteristics to crop growth. In this study, simple ranking was used to rate land characteristics from 1 (least important) to 2 (most important) for cotton and from 3 to 1 for soybean and from 5 to 1 for rice and from 4 to 1 for wheat. This ranking (Table 1) was based on the literature[16,17], expert opinion and a preliminary study undertaken to identify the importance of land characteristics to agricultural land use in the study area. To ensure that weights sum up to unity, the rank r_i of a land characteristic A was converted to weight w_i using the equation

$$w_i = \frac{r_i}{\sum_{i=1}^{n} r_i}. \tag{3}$$

Results and discussion

Identification of minimum datasets

The MDS identified for rice and wheat in IGP and cotton and soybean in the BSR are presented in Tables 1 and 2

Table 4. Values of selected parameters of MDS for wheat in IGP

Soil series	ESP	BD (Mg m^{-1})	ECe (dS m^{-1})	T_{min} (°C)
Mashitawali	12.7	1.66	1.71	10.80
Shakhi-2	6.9	1.44	0.97	21.00
Zarifaviram	6.0	1.58	0.92	19.60
Sakit	4.7	1.33	5.20	20.50
Singhpura	3.6	1.74	0.11	20.80
Fatepur	2.7	1.53	0.21	19.30
Itwa	4.4	1.55	1.29	21.50
Gopalpur	1.8	1.45	0.13	20.50
Ekchari	2.6	1.49	0.10	23.20
Haldi	3.0	1.38	0.21	17.00
Madhpur	1.7	1.50	0.11	23.50
Singbhita	2.3	1.22	0.03	11.10
Seoraguri	2.8	1.28	0.06	21.60
Nayanpur	1.7	1.33	0.06	22.80
Sagar HM	12.1	1.39	0.55	20.80

Values are for 0–150 cm weighted mean.

Table 5. Values of selected parameters of MDS for cotton and soybean in BSR

Soil series	sHC (mm h^{-1})	ESP (dS m^{-1})	Clay (%)
Teligi	0.8	19.5	68.6
Bhola	45.6	6.6	37.2
Sarol	29.5	1.3	57.7
Sokhda	30.9	3.3	26.0
Nimone	14.6	26.1	62.0
Vasmat	19.6	8.2	61.5
Paral	12.2	8.8	58.1
Achmati	6.6	6.2	69.8
Nandyal	0.7	17.7	58.7
Kasireddipalli	12.8	2.2	56.9
Tenali	11.2	8.4	67.5
Coimbatore	11.0	1.9	68.8
Sidalghatta	4.2	9.3	43.9
Kovilpatti	3.4	9.8	37.4
Nabibagh	9.2	23.1	69.0
Panjari	6.0	2.0	55.4
Gulguli	3.9	1.9	56.8

Values are for 0–150 cm weighted mean.

Table 6. Ranks and values of different indices for MDS parameters for rice and wheat

Selected parameter	Rank	Standard index (x_i)	Dispersion index (a_i)	Weightage (w_i)
Rice				
Rainfall (mm)	5	750	0.001	0.33
Clay (%)	4	> 25	0.02	0.27
ESP	3	< 40	0.01	0.20
COLE	2	> 0.06	0.02	0.13
Slope (%)	1	< 3	0.01	0.07
Wheat				
BD (Mg m^{-3})	4	< 1.33	0.004	0.40
ESP	3	< 40	0.036	0.30
ECe (dS m^{-1})	2	< 4	0.002	0.20
T_{min} (°C)	1	< 22	0.01	0.10

Table 7. Ranks and values of different indices for MDS parameters for cotton and soybean

Selected parameter	Rank	Standard index (x_i)	Dispersion index (a_i)	Weightage (w_i)
Cotton				
sHC (mm h^{-1})	2	10–15	0.012	0.67
ESP	1	< 5	0.018	0.33
Soybean				
Clay (%)	3	27–35	0.008	0.50
sHC (mm h^{-1})	2	10–15	0.010	0.33
ESP	1	< 8	0.010	0.17

Table 8. Membership functions for MDS constituents for rice in IGP

Soil series	Rainfall (mm)	Texture	ESP	COLE	Slope (%)
Mashitawali	0.004	1.00	1.00	1.00	0.20
Shakhi-2	0.005	1.00	1.00	1.00	0.04
Zarifaviran	0.88	1.00	1.00	1.00	0.04
Sakit	1.00	0.03	1.00	0.50	0.04
Singhpura	0.91	0.13	1.00	1.00	0.04
Fatepur	0.95	1.00	1.00	1.00	0.04
Itwa	1.00	0.50	1.00	1.00	0.04
Gopalpur	1.00	0.00	1.00	0.01	0.20
Ekchari	1.00	0.03	1.00	0.08	0.50
Haldi	1.00	1.00	1.00	1.00	0.04
Madhpur	1.00	0.03	1.00	0.04	0.20
Singbhita	1.00	1.00	1.00	1.00	0.04
Seoraguri	1.00	1.00	1.00	1.00	0.04
Nayanpur	1.00	0.25	1.00	1.00	0.04
Sagar HM	1.00	0.01	1.00	0.16	0.04

respectively, along with justification for their identification. The values of the MDS constituents (weighted means, 0–150 cm) for each benchmark site in the IGP for rice are presented in Table 3 and those for wheat are presented in Table 4. The values of the MDS constituents (weighted means, 0–150 cm) for each benchmark site in the BSR for cotton and soybean are presented in Table 5.

Land evaluation using fuzzy modelling-based approach

The ranks and statistics of standard indices, dispersion indices and weightage (computed through ranking approach) for rice and wheat are presented in Table 6, and for cotton and soybean are given in Table 7. The same were required for developing membership functions.

A value of dispersion index 0.012 developed for sHC for cotton (Table 7) implies that the various soil units have their sHC belongingness to the ideal value scattered within a band of 0.012 measure. Standard indices (x_i) for the MDS components for cotton, soybean, rice and wheat were finalized on the basis of their point/range values in the highly suitable class[16] and knowledge of experts on the soils and crops of IGP and BSR.

Weightages were assigned to each parameter based on the relative importance of that parameter to the cultivation

Table 9. Membership functions for MDS constituents for wheat in IGP

Soil series	EC (dS m^{-1})	BD (Mg m^{-3})	ESP	T_{min} (°C)
Mashitawali	1.00	0.03	1.00	1.00
Shakhi-2	1.00	0.23	1.00	1.00
Zarifaviran	1.00	0.05	1.00	1.00
Sakit	1.00	1.00	1.00	1.00
Singhpura	1.00	0.02	1.00	1.00
Fatepur	1.00	0.08	1.00	1.00
Itwa	1.00	0.07	1.00	1.00
Gopalpur	1.00	0.20	1.00	1.00
Ekchari	1.00	0.12	1.00	0.32
Haldi	1.00	0.59	1.00	1.00
Madhpur	1.00	0.11	1.00	0.23
Singbhita	1.00	1.00	1.00	1.00
Seoraguri	1.00	1.00	1.00	1.00
Nayanpur	1.00	1.00	1.00	0.51
Sagar	1.00	0.50	1.00	0.32

Table 10. Joint membership functions (JMFs), composite land indices (CLI) and land classes of MDS parameters for rice in IGP

	JMF						
Soil series	Rainfall (mm)	ESP	COLE	Clay (%)	Slope (%)	CLI	Land class
Mashitawali	0.01	0.2	0.13	0.26	0.01	61.40	II
Shakhi	0.01	0.2	0.13	0.26	0.02	62.00	II
Zarifaviram	0.30	0.2	0.13	0.26	0.02	90.92	I
Sakit	0.34	0.2	0.07	0.01	0.02	63.22	II
Singhpura	0.31	0.2	0.13	0.03	0.02	69.30	II
Fatepur	0.32	0.2	0.13	0.26	0.02	93.30	I
Itwa	0.34	0.2	0.13	0.13	0.02	82.00	I
Gopalpur	0.34	0.2	0.00	0.01	0.01	56.54	III
Ekchari	0.34	0.2	0.01	0.01	0.03	59.00	III
Haldi	0.34	0.2	0.13	0.26	0.02	95.00	I
Madhpur	0.34	0.2	0.01	0.01	0.01	57.00	III
Singbhita	0.34	0.2	0.13	0.26	0.02	95.00	I
Seoraguri	0.34	0.2	0.13	0.26	0.02	95.00	I
Nayanpur	0.34	0.2	0.13	0.06	0.02	75.00	II
Sagar	0.34	0.2	0.02	0.02	0.01	59.00	II

Table 11. Joint membership functions (JMFs), composite land indices (CLI) and land classes for wheat in IGP

	JMF					
Soil series	ESP	BD (Mg m^{-3})	EC (dSm^{-1})	T_{min} (°C)	CLI	Land class
Mashitawali	0.3	0.01	0.2	0.1	51.28	II
Shakhi	0.3	0.09	0.2	0.1	69.17	II
Zarifaviran	0.3	0.02	0.10	0.10	51.79	III
Sakit	0.3	0.06	0.2	0.10	55.52	II
Singhpura	0.3	0.01	0.2	0.10	61.08	II
Fatepur	0.3	0.06	0.2	0.10	65.52	II
Itwa	0.3	0.03	0.2	0.10	63.02	II
Gopalpur	0.3	0.09	0.2	0.10	69.17	II
Ekchari	0.3	0.02	0.2	0.03	55.05	III
Haldi	0.3	0.12	0.2	0.10	72.31	II
Madhpur	0.3	0.02	0.2	0.02	54.46	III
Singbhita	0.3	0.40	0.2	0.10	100.00	I
Seoraguri	0.3	0.40	0.2	0.10	100.00	I
Nayanpur	0.3	0.17	0.2	0.05	72.05	II
Sagar	0.3	0.04	0.2	0.03	57.17	III

of a crop and were based on local experts' knowledge and the available literature and the consequent ranking. The sHC, for instance, being the most important parameter for cotton (in BSR)[17] was assigned the maximum weightage of 0.67.

The membership functions of MDS constituents for rice and wheat are presented in Tables 8 and 9 respectively. The joint membership functions (JMFs), composite land indices (CLI) and land classes for rice and wheat are presented in Tables 10 and 11 respectively. The JMFs are the weighted values of MF, i.e. a product of membership functions and weightage. The CLIs are the sum of the JMF values of the land characterization.

The membership functions of the relevant parameters in the given land units under BSR for cotton and soybean are presented in Tables 12 and 13 respectively. The membership functions (or values) indicate the degree of suitability at a given location with respect to a given land characteristic. On an 0–1 scale, any parameter having a membership of 1 (highly suitable class) in any land unit suggests that it has the complete belongingness to a particular class. The membership value of sHC for Bhola series for cotton is 0.94 (Table 12), which implies that the parameter has a partial belongingness of 94% to that class.

In Table 13, a membership value of 0.28 was generated for sHC in Sokhda soil for soybean that suggests (a) suitability of the location is 28% of the ideal requirement of the land characteristic, and (b) the site has a limitation of 72%. Membership value of ESP for cotton is the lowest (0.37), whereas that for sHC is the highest (1.00). The JMF and CLI values for cotton and soybean are presented in Tables 14 and 15 respectively. For cotton, the CLI was lowest (56.9) and highest (99.6) for Teligi and Sokhda soils respectively.

The suitability classes for the crops were identified by placing the CLI values (of the land units) in a set of equally spaced classes on a 0–100 scale, with a 20 unit gradation. The suitability classes of the given land units are indicated for cotton (Table 14) and soybean (Table 15). Table 14 indicates that Bhola, Sarol, Sokhda, Vasmat, Paral, Achmati, Coimbatore, Kasireddipalli and Panjri soil series belong to class I; Tenali, Sidalghatta, Kovilpatti, Nimone, Nabibagh and Gulguli to class II, and Teligi and Nandyal soils to class III for cotton.

The fact that an area has a relatively high suitability index does not automatically imply that high yields would be obtained. This is for the simple reason that the fuzzy approach does not incorporate yield influencing management decisions, such as timing of planting or dose of fertilizer application. The results simply quantify how good (or bad) is the soil for the particular crop. This is exactly why the land indices obtained from this approach were not correlated with the crop yield to judge accuracy of the approach, which stands sound logic.

Since fuzzy modelling-based land evaluation was identified as a relatively robust method, superior to the conventional parameter method, the results (i.e. land indices) obtained thereof were made use of in developing the thresholds of the land characteristics. We made an effort to develop the threshold values for the MDS parameters. Three criteria were considered. These are: (i) average of the parametric values in the community, (ii) 50% of the ideal value of a parameter and (iii) parametric value corresponding to 80% of the highest value of membership function (Figure 3). Finally, the minimum/maximum value was developed as the threshold for that land parameter. Thresholds so developed for the MDS constituents of the four crops are presented in Table 16. The threshold values developed, say, for the two

Table 12. Membership functions for MDS constituents for cotton in soils of BSR

Soil series	sHC (mm h^{-1})	ESP
Teligi	0.58	0.56
Bhola	0.94	0.99
Sarol	1.00	0.95
Sokhda	1.00	0.99
Nimone	0.94	0.37
Vasmat	1.00	0.96
Paral	0.89	0.95
Achmatti	0.74	0.99
Nandyal	0.57	0.62
Kasireddipalli	0.91	0.97
Tenali	0.56	0.96
Coimbatore	0.86	0.97
Sidalghatta	0.67	0.93
Kovilpatti	0.64	0.92
Nabibagh	0.81	0.44
Panjari	0.72	0.97
Gulguli	0.66	0.98

Table 13. Membership functions for MDS constituents for soybean in soils of BSR

Soils	Clay (%)	sHC (mm h^{-1})	ESP
Teligi	0.52	0.54	0.43
Bhola	0.99	0.09	1.00
Sarol	0.70	0.32	1.00
Sokhda	0.93	0.28	1.00
Nimone	0.63	1.00	0.23
Vasmat	0.64	0.82	1.00
Paral	0.70	1.00	0.99
Achmati	0.50	0.89	1.00
Nandyal	0.69	0.53	0.51
Kasireddipalli	0.72	1.00	1.00
Tenali	0.54	1.00	1.00
Coimbatore	0.52	1.00	1.00
Sidalghatta	0.94	0.74	0.98
Kovilpatti	0.99	0.69	0.97
Nabibagh	0.51	0.99	0.30
Panjari	0.75	0.86	1.00
Gulguli	0.72	0.72	1.00

Table 14. Joint membership functions, composite land indices and land classes for cotton in BSR

Soil series	JMF		CLI	Land class
	sHC (mm h^{-1})	ESP		
Teligi	0.39	0.18	56.9	III
Bhola	0.63	0.33	95.7	I
Sarol	0.67	0.31	98.4	I
Sokhda	0.67	0.33	99.6	I
Nimone	0.63	0.12	75.5	II
Vasmat	0.67	0.32	98.7	I
Paral	0.60	0.31	91.0	I
Achmati	0.49	0.33	82.1	I
Nandyal	0.38	0.20	58.8	III
Kasireddipalli	0.61	0.32	92.8	I
Tenali	0.37	0.32	68.8	II
Coimbatore	0.58	0.32	89.5	I
Sidalghatta	0.45	0.31	75.5	II
Kovilpatti	0.43	0.30	73.6	II
Nabibagh	0.54	0.15	69.0	II
Panjri	0.48	0.32	80.1	I
Gulguli	0.44	0.32	76.0	II

Table 15. Joint membership functions, composite land indices (CLI) and land classes for soybean in BSR

Soil series	JMF			CLI	Land class
	Clay (%)	sHC (mm h^{-1})	ESP		
Telgi	0.18	0.07	0.26	51.48	III
Bhola	0.03	0.17	0.50	69.98	II
Sarol	0.11	0.17	0.35	63.03	II
Sokhda	0.09	0.17	0.47	73.30	II
Nimone	0.33	0.04	0.32	68.54	II
Vasmat	0.27	0.17	0.32	76.27	II
Paral	0.33	0.17	0.35	84.92	I
Achmati	0.30	0.17	0.25	71.96	II
Nandyal	0.18	0.09	0.35	60.93	II
Kasireddipalli	0.33	0.17	0.36	86.10	I
Tenali	0.00	0.17	0.27	44.09	III
Coimbatore	0.33	0.17	0.26	76.15	II
Sidalghatta	0.25	0.17	0.47	88.44	I
Kovilpatti	0.23	0.16	0.50	89.25	I
Nabibagh	0.33	0.05	0.26	63.91	II
Panjri	0.28	0.17	0.37	82.94	I
Gulguli	0.24	0.17	0.36	77.24	II

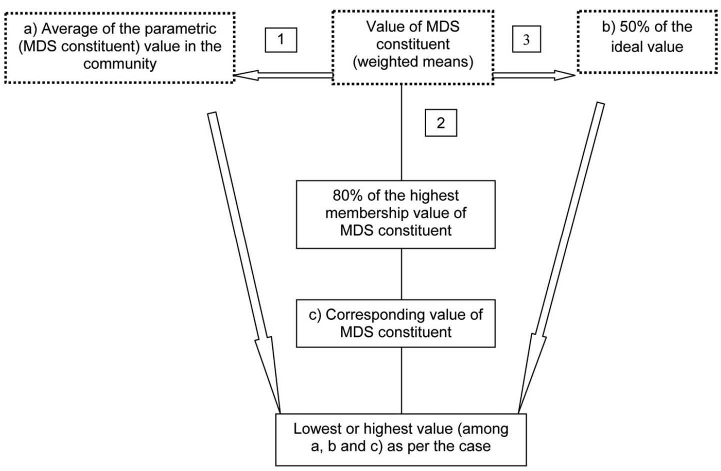

Figure 3. Schematic diagram for developing threshold values of MDS constituents for cotton, soybean, rice and wheat using fuzzy modelling.

Table 16. Threshold values developed of MDS constituents for selected crops in the IGP and BSR by different approaches

Crop	MDS constraints	Threshold value
Indo-Gangetic Plains		
Rice	Rainfall (mm)	< 600
	ESP	> 5
	COLE	< 0.52
	Clay (%)	< 21
	Slope (%)	> 2.4
Wheat	ECe (dS m^{-1})	> 6
	BD (Mg m^{-3})	> 1.45
	ESP	> 32.0
	Minimum temperature (°C)	> 20
Black soil regions		
Cotton	sHC (mm h^{-1})	< 25
	ESP	> 4.0
Soybean	Clay (%)	> 27
	sHC (mm h^{-1})	< 25
	ESP	> 4.0

MDS components for cotton, have certain clear-cut implications. For example, a threshold value of 24.7 mm h^{-1} is developed for sHC in case of land evaluation for rainfed cotton (Table 16), which implies that a value of less than 24.7 mm/h would trigger problems for cotton production in the BSR. Similarly, an ESP value of more than 4.0 would trigger production problems for the same crop in the BSR.

Conclusion

The fuzzy model land evaluation approach helps in: (i) overcoming limitations of abrupt boundary of land classes and (ii) identification of MDS of land characteristics. The robustness of this method and its ability to develop threshold values of MDS parameters, establish it as a sound and intuitive land evaluation technique for evaluating suitability of the selected benchmark soils in the IGP for rice and wheat and in the BSR for cotton and soybean.

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