Soil Nutrient Based Land Suitability Analysis for Lentil Crop in Tarakeswar, Hooghly, West Bengal

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BACKGROUND: Land suitability assessment can inform decisions on land uses suitable for maximizing crop yield while making best use, but not impairing the ability of natural resources such as soil to support development. We assessed the suitability of lentil to be produce in 300 ha land of Tarakeswar block of Hooghly district West Bengal.

METHODS: Suitability criteria included eight criterion, such as: soil texture (ST), electrical conductivity (EC), organic carbon (OC), available nitrogen(N), available phosphorous (P), available potassium(K) and available zinc (Zn). We modified and used a novel set of techniques to assess suitability: Analytical Hierarchy Process (AHP) pairwise comparison matrix and Geographic Information System (GIS) software.

RESULT: The exponential model generated by Ordinary Kriging was used to estimate the lentil land use suitability. Suitability distribution of deep layer found nearly 42% area under suitability class, i.e. S, which may be used for growing the crop profitably.

KEY WORDS: AHP, GIS, Land suitability, Lentil, Soil profile.
majority of the roots will usually be found in the top 18cm of the soil profile (Sell and Aakre, 2019).

The objective of the study is to determine the soil nutrient suitability based on soil profile for adopting lentil crop in Tarakeswar block, Hooghly district of West Bengal by integrating AHP ranking model in GIS software environment.

**MATERIALS AND METHODS**

**Study area**
Hooghly district is one of the agriculturally prosperous districts of the state of West Bengal, India. The total population is 55,20,389 (as per census 2011), with density of 1753/ sq. km. The district is a completely flat land with elevation below 200 meters. Geologically, the area comes under Quaternary formation with recent alluvium. The climate of the study area is tropical and humid. The temperature normally varies from 24-40°C during summer and from 7–26°C during winter (Fig 1).

The research was conducted in the Tarakeswar block of Hooghly District. This study region covers an area of 291 hectares and is situated at 22° 48’ 00” N and 88° 04’ 00” E in UTM system for zone 45 WGS-1984 datum with population of 179,148 in 2011 census. The base map of the study area is in the scale of 1:50,000 developed by Survey of India, 2011 with Sheet no. F45K1(79B/1). Nine ground control points (GCPs) were supplied using eTrex 20 GPS Receiver (Garmin Ltd., Olathe, Kansas, USA) for image digitization in Arc GIS 10.1 (ESRI, Redlands, California, USA) software environment. According to agro-climatic zoning, Tarakeswar is part of the Gangetic alluvial zone with clay loam type of soil and is very fertile (Bhowmik et al., 2014). Though, crop production of this region is dominated by rice and potato, lentil is the only legume crop with the best current market price in the study area. Demands for consuming legume crops are sound in order to motivate rural farmers towards this crop cultivation.

**Sample data collection and preparation**
Field studies were carried out to identify the reality of the physiographic farm units and soils interpretation. Soil sampling points were identified by coordinate point recorded from GPS receivers. Initial sampling was conducted by auger and investigated further if changes as outlined by Soil survey Staff (2012) warranted description of the site as a different soil layer. A total of seventy observation points for two soil layers (0-20cm top layer; 20-40cm deep layer) were used to check the accuracy of land use suitability status. Soil samples were collected from two soil layers, air dried, crushed, sieved through <2mm screen. These samples were analyzed using standard methods (Soil Survey Staff, 2014).

In this study, eight main parameters were selected for lentil land suitability classes after an extensive literature review (Table 1).

**Selection of the effective criteria for land use suitability**
Analytical hierarchy process (AHP) technique is one of the most advanced MCDM techniques used in GIS-based

| Parameters          | Unit         | Highly suitable (S₁) | Moderate suitable (S₂) | Marginal suitable (S₃) | Not suitable (N) |
|---------------------|--------------|----------------------|------------------------|------------------------|------------------|
| Soil pH             | Reaction     | 6.0-7.5              | 7.5-8.0                | 8.0 – 8.5              | >8.5             |
| Organic carbon (OC) | %            | >1.5                 | 1.0-1.5                | 0.5-1.0                | < 0.5            |
| Electrical conductivity (EC) | (dS/m) | 0-1.0               | 1.0-1.5                | 1.5-2.0                | > 2.0            |
| Available nitrogen (N) | ppm          | >7.5                 | 5.0-7.5                | 2.5-5.0                | <2.5             |
| Available phosphorous (P) | ppm    | > 11                 | 8-11                   | 5-8                    | <5               |
| Available potassium (K) | ppm          | >5                   | 10-15                  | 5-10                   | <5               |
| Available zinc (Zn) | ppm          | >1.0                 | 0.8-1.0                | 0.5-0.8                | <0.5             |
| Soil texture (ST)   | Class        | Loam, silty loam, sandy clay loam | Silty clay, clay loam | Sandy loam, clay loam | clay >60%        |

Source: Sys et al. (1991; 1993); NBSS and LUP (1990); FRG-BARC (2012).
suitability procedures (Din and Yunusova, 2016) because of its appropriateness for making decisions on the basis of multiple factors ranked according experts’ preferences. In the current study, the pair wise comparisons of the various criteria were organized into a square matrix. The diagonal elements of the matrix were scored 1 (Table 2). Weightings were derived by expert opinion according to a questionnaire of twenty experts in the field of agronomy, soil science, general agriculture and KVK specialist etc. and analyzed using MATLAB 2016b software to reach final weights. In this analysis, if the consistency ratio was lower than 0.1 in node and factors matrices. This degree of consistency of the pair-wise comparison matrices is considered acceptable (Saaty and Vargas, 2013).

The consistency of the matrix of order n was evaluated. If this consistency index failed to reach a threshold level, the answers from the comparisons were re-examined. The consistency index, CI, was calculated as per Equation (1):

\[ CI = \frac{\lambda_{\text{max}} - n}{n-1} \]  

Where, 
\( \lambda_{\text{max}} \) = largest or principal eigenvalue of the matrix;  
\( n \) = order of the matrix.

This CI can be compared to that of a random matrix, RI, such that the ratio, CI/RI, is the consistency ratio, CR. As a general rule, a value of CR ≤ 0.1 should be maintained for the matrix to be consistent. In other words, the results for all RIs for the single and general hierarchies were lower than 0.1. Homogeneity of indicators within each group, a smaller number of factors in the group and better understanding of the decision problem improves the consistency index (Saaty 1993).

**Interpolation analyses for suitability**

In the present study, five main interpolation methods, namely Inverse Distance Weighing (IDW), Empirical Bayesian kriging (EBK), Radial Basis Function (RBF), Local Polynomial Interpolation (LPI) and ordinary kriging (OK) were employed for predicting the spatial distribution of soil nutrient suitability for lentil. Kriging is a geostatistical technique similar to IDW which employs a linear combination of weightings at known points to estimate the value at an unknown point. Bayesian kriging allows uncertainty in the model parameters to be reflected in the prediction intervals, thus providing a more reliable prediction of the parameter of interest (Diggle and Ribeiro, 2002); where local polynomial interpolation is sensitive to the neighborhood distance and a small searching neighborhood may create empty areas in the prediction surface. Kriging uses a semivariogram method to determine the spatial correlation between two points in that weighing change according to the spatial arrangement of the samples Webster and Oliver, 2001). In contrast to other estimation procedures, kriging provides a measure of the uncertainty of the estimation. The Root Mean Square Error (RMSE) method was used to compare the interpolation techniques. The lowest RMSE indicates the most accurate prediction, with estimates determined by using the following formula (2):

\[ \text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n} (\hat{z}(s_i) - z(s_i))^2}{n}} \]  

Where  
\( \hat{z}(s_i) \) - the predicted value.  
\( z(s_i) \) - the observed (known) value.  
\( n \) - the number of values in the dataset (Webster and Oliver, 2001).

**RESULTS AND DISCUSSION**

**Soil physico-chemical properties**

Alluvial land and its soils often show spatial variations in their properties over short distances. The descriptive statistics for this study are presented in Table 3. The pH values of the soil samples ranged between 4.11 and 6.33 and electrical conductivity ranged from 0.10 dS m\(^{-1}\) to 1.73 dS m\(^{-1}\). The soil texture class widely varied from sandy loam to clay, with clay content ranging 22% and 63% and sand between 11% and 65%. The mean values for organic matter is 0.5%. As for macronutrients, available P, K and Zn levels showed high variation. Available N varied between 10 ppm (parts per

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**Table 2:** Fundamental scale of absolute numbers used in questionnaire.

| Intensity of importance | Definition | Explanation |
|-------------------------|------------|-------------|
| 1                       | Equal importance | Two activity contribute equally to the objective |
| 2                       | Weak or slight | Experience and judgment slightly favour one activity over another |
| 3                       | Moderate importance | Experience and judgment strongly favour one activity over another |
| 4                       | Moderate plus | Demonstrated importance |
| 5                       | Strong importance | An activity is favoured very strongly over another; its dominance demonstrated in practice |
| 6                       | Strong plus | The evidence favouring one activity over another is of the highest possible order of affirmation |
| 7                       | Very strong | Used to represent a compromise between the priorities listed above |
| 8                       | Very, very strong | |
| 9                       | Extreme importance | |
| 2,4,6,8                 | Intermediate value | |

Source: Saaty, 1980.
The assignment of the score for each soil sample comprised of three main steps. Firstly, the ranks of the parameter were decided as per recommendations by the local experts. Secondly, AHP technique was performed to generate the evaluation scores or eigenvector. Principal eigenvalue ($\lambda_{max}$) and Consistency Index (CI) were estimated at 8.57 and 0.08, respectively. Consistency ratio (CR) was estimated and found to be 0.06 (<0.10, within the limit). So, the weightage estimated are valid and can be used further for lentil land suitability estimation. Whereas, for lentil Soil texture (0.345) was assigned highest weightage value and available nitrogen (N) (0.021) lowest weightage value (Table 5).

These results are consistent with natural and artificial factors for land use suitability and soil texture received the highest value because lentil cultivation requires soil with high water retention capacity which stems from the high clay fraction. pH content received the second weightage value due to its influence on the biological and physico-chemical properties of soils, including the development of soil acidity, aggregation and supply of nutrient elements and effects on cation exchange capacity. On the other hand, this parameter can be affected by soil and lentil cultivation practices.

**Suitability analysis**

As lentil crop is deep rooted, the soil suitability study for both top and deep layer are important to select the best crop for a particular field. Suitability distribution maps for individual soil parameters for the crop for both the layers were developed in GIS environment (Fig 2) based on individual suitability range. Combined suitability distribution map for lentil using the AHP weightage after validation was also developed for both the layers (Fig 3). Even during deep ploughing the deep soil layer may come up and contribute to the shallow rooted multiple crops such as rice and potato etc in crop rotation.

**Top layer**

Lentil suitability distribution map was developed for top layer using AHP weightage in GIS environment (Fig 3). The analysis revealed that around 12.4% of total crop area is in (S1) ‘highly suitable’ zone, 54.6% area is in (S2) ‘moderately suitable’ zone (Table 6). A substantial portion (30%) of the

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### Table 3: Descriptive statistical analysis of physical and chemical properties of soil samples (n=70).

| Indices     | pH | Log pH | EC (ds/m) | Log EC | OC (%) | N (ppm) | P (ppm) | K (ppm) | Zn (ppm) | Sand (%) | Silt (%) | Clay (%) |
|-------------|----|--------|-----------|--------|--------|---------|---------|---------|---------|----------|----------|----------|
| Mean        | 4.87 | 1.57  | 0.56      | -0.70  | 0.54   | 27.9    | 42.64   | 3.92    | 41.4    | 2.23     | 42.64    | 39.2     |
| SD          | 0.57 | 0.11  | 0.31      | 0.53   | 0.18   | 8.72    | 60.8    | 29.64   | 6.42    | 13.75    | 5.57     | 9.48     |
| Skewness    | 1.14 | 0.92  | 1.66      | -0.40  | 0.01   | 0.96    | -1.64   | 0.58    | -0.59   | 0.42     | 0.27     | 0.77     |
| Kurtosis    | 0.40 | 2.94  | 3.92      | 4.07   | 0.36   | 2.23    | 1.07    | -0.25   | -1.7    | 0.30     |         |          |
| Minimum     | 4.11 | 1.41  | 0.10      | -2.30  | 0.13   | 10.04   | 35.07   | 25.90   | 1.16    | 11.7     | 10.0     | 22.3     |
| Maximum     | 6.33 | 1.84  | 1.73      | 0.54   | 0.95   | 55.2    | 231.63  | 150.73  | 3.88    | 66.4     | 28.7     | 63.6     |
| CV (%)      | 11.69 | 54.37 | 33.1      | 31.3   | 30.84  | 38.5    | 28.0    | 32.2    | 30.7    | 24.2     |         |          |

Note: EC-electrical conductivity; OC- organic carbon; N- Available nitrogen; P- available phosphorous; K- Available potassium; Zn- Zinc; pH- logarithmic change.

### Table 4: Cross-validation according to interpolation methods.

| Soil parameters | IDW | EBK | RBF | LPI | OK |
|-----------------|-----|-----|-----|-----|----|
| pH              | 0.355 | 0.322 | 0.359 | 0.343 | 0.340 |
| EC (ds/m)       | 0.300 | 0.269 | 0.283 | 0.262 | 0.273 |
| OC (%)          | 0.124 | 0.119 | 0.120 | 0.116 | 0.123 |
| N (ppm)         | 10.807 | 9.121 | 10.196 | 9.342 | 10.076 |
| P (ppm)         | 66.717 | 61.06 | 63.817 | 61.369 | 79.573 |
| K (ppm)         | 30.802 | 28.036 | 29.086 | 27.750 | 29.358 |
| Zn (ppm)        | 0.444 | 0.446 | 0.449 | 0.454 | 0.473 |
| Sand (%)        | 7.577 | 7.623 | 7.640 | 7.930 | 7.806 |
| Silt (%)        | 4.017 | 3.797 | 3.912 | 3.688 | 3.995 |
| Clay (%)        | 5.375 | 5.434 | 5.193 | 5.570 | 5.714 |

Note: RMSE- root mean square error, IDW-inverse distance weighting, EBK- Empirical Bayesian kriging, LPI- local polynomial interpolation, RBF-radial basis function and OK-ordinary kriging.

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Table 5: Contribution weight of soil parameters to lentil land suitability estimation by the AHP technique (n=8).

| Parameter | Weightage |
|-----------|-----------|
| ST        | 0.345     |
| pH        | 0.218     |
| Zn        | 0.153     |
| EC        | 0.107     |
| OC        | 0.077     |
| P         | 0.046     |
| K         | 0.033     |
| N         | 0.021     |

Note: CR=0.06 (<0.10), ST- soil texture, OC- organic carbon, N- available nitrogen, P- available phosphorous, K- available potassium, Zn- zinc level, n-number of parameters.
area is under ‘marginal suitable’ zone and lowly 3% area is under (N)-‘not suitable’ zone. Together, the two categories ‘highly suitable’ and ‘moderate suitable’ make up 67% of the total area, which may be dedicated for lentil crop, if potato is not profitable in those area for real market price condition as *rabi* crop.

**Deep layer**

Suitability map for lentil crop in the deep soil layer is also carried out using the AHP weightage in GIS environment (Fig 3). The analysis showed that 15.8%, 26.8%, 50.2% and 7.2% of lands (Table 6) are classified as **S**$_1$,$S_2$,$S_3$, and **N** suitability classes, respectively, for lentil crop. Area under (**S**$_3$)-‘marginal suitability’ is enhanced drastically showing low level of nutrient availability in the deep soil layer.

AHP is helpful in assigning the relative weights of the criteria and validating them. GIS is used to identifying study locations, geographic data manipulating and map processing and final presentation of land suitability maps. 

Looking at the suitability distribution of deep layer nearly 42% area come under suitability class, i.e. **S**$_2$ may be used for growing the crop profitably. Lentil crop may also be recommended based on higher sale value of lentil compared to other legume crops (White *et al*., 2006). The legumes crops will enhance soil fertility through nitrogen fixation, which may be introduced as alternative crop in *rabi* season. Additionally, multiple seasons may provide better results for selecting suitable land for the crop.

**CONCLUSION**

The land suitability analysis was carried out for an area of the 300 ha for lentil production located in the Tarakeswar block of Hooghly district, West Bengal. Across farm plots, the most important factors limiting lentil production were ST, EC, OC, N, P, K and Zn. The AHP technique showed good potential to determine criteria weights with different relative importance, based on expert opinion, while the integration of GIS with an AHP pairwise comparison matrix technique provided a realistic assessment of productivity, independent of agricultural practice (e.g., fertilizer applications). Soil profile based study gave a new insight towards carrying out land suitability studies for tap root crops, like lentil. Farmers throughout the study area had conflicting opinions on yield reduction in their fields, particularly during *rabi* season. The situation reinforces the need for detailed soil survey and mapping studies in areas with alluvial soils.

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