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GIS based Analytical Hierarchy Process for Analysis of Land Suitability for Sesame around Thermal Power Plant

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Abstract

Geographic Information System (GIS) based Analytical Hierarchy Process (AHP) model has been used to assess land suitability for sustainable agricultural planning around the Kolaghat Thermal Power Plant (KTPP) in the district Purba Medinipur, West Bengal, India. For judging crop potentiality, pair-wise comparisons between the influential factors in AHP have shown the superiority of the soil chemical properties with the highest relative weight of rainfall (0.171738), organic carbon (0.154899) and soil pH (0.123876) for determination of sesame suitability. The lowest weight allocated to flood is 0.020909 and 0.35716 for average minimum temperature. Consistency Ratio (CR) has been calculated and it is < 0.1 which is 0.097875 for all factors which indicates the correctness of the AHP model. In reality, sesame is cultivated in 5.12% area of total area of Kolaghat whereas GIS based AHP model suggests 21.68% area is suitable for economic cultivation of sesame. Moderately suitable areas (78.32%) for sesame need improvement of some soil properties such as soil pH and organic carbon. People are cultivating comparatively in very less area with marginally suitable crops which jeopardize their socio-economic status. GIS based AHP evaluation promotes agricultural and environmental sustainability around the coal-fired thermal power plant.

Keywords: GIS Technology; Analytical Hierarchy Process; Land Suitability; Agricultural Sustainability.

INTRODUCTION

Geographic information system (GIS) is a set of tools for collection, storing, retrieving, transforming, analyzing and displaying spatial and non-spatial data (Burrough, 1986). It can improve the efficiency of data processing, can help to solve data integration problems and can support spatial analysis (Bronsveld *et al.*, 1994; Rossiter, 1996). Moreover it can help to improve the description of land utilization types required for land evaluation (Van de Putte, 1989; Bronsveld *et al.*, 1994; Rossiter, 1995). Lal *et al.*, (1993) extended the scope of applicability of site-specific crop simulation models such as DSSAT (decision support system for agro-technology transfer) to regional planning productivity and policy analysis by combining their capabilities with ARC/INFO GIS. Singh et al., (1993) demonstrated the use of GIS to investigate nitrogen fertilizer efficiency in Maharashtra state, using sorghum crop simulation model coupled with a GIS. Analytic hierarchy process firstly developed by Saaty (1980), envisages a hierarchical model for determination of land

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suitability with best alternatives (Malczewski 2006; Cengiz and Akbulak 2009; Roig-Tierno *et al*. 2013). Kolaghat Thermal Power Plant (KTPP)is situated at geo-referencing point of 22.467°N and 87.843°E on the right bank of the Rupnarayan river in the district of Purba Medinipur, West Bengal, India (Fig. 1). The KTPP has a total installed capacity of 1260 MW with six units, generating about 7500-8000 metric ton of fly ash every day by consuming a total of 18000 ton of coal (Das gupta and Paul, 2011). Although the plant has a number of benefits, the lack of treatment of the fly ash generated from this power plant has been detrimental to the productivity and quality of the main agricultural crops of the surrounding area and is also responsible for some changes in the land use pattern (Adak et al., 2016). Kolaghat Block is the most affected area covering 15480.51 hectare of land.

The present effort of study is to determine land suitability with the help of GIS based Analytical Hierarchy Process for the best alternative uses of land around the coal-burnt thermal power plant.

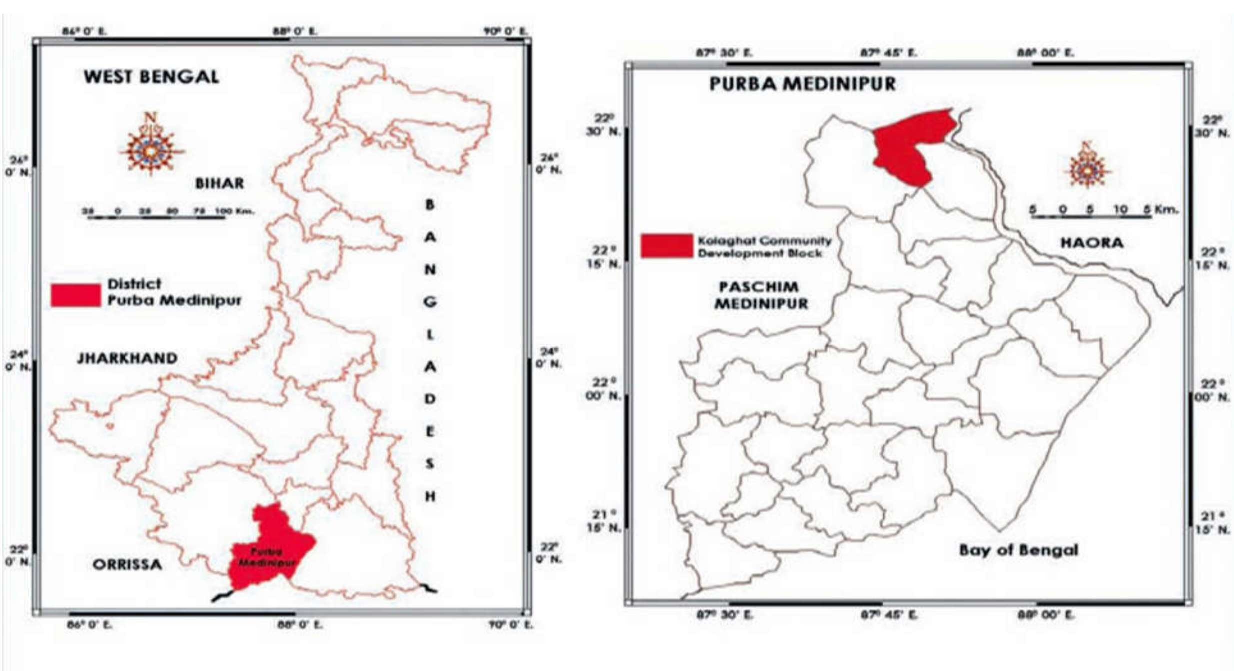
MATERIALS AND METHODS

Thirteen soil profiles have been evaluated throughout the study area in order to manage the land resources for agricultural sustainability. The attributes / factors considered for determination of land suitability are base saturation, organic carbon, cation exchange capacity, pH, soil texture, drainage, occurrence of flood, slope, average minimum and maximum temperature, relative humidity, rainfall. Climate data especially rainfall, humidity and temperature have been recorded for the year of 2015, 2014, 2013. The particles size distribution (sand, silt, clay) has been determined by the hydrometer method (Buoycos, 1962). The pH of the soil samples have been estimated in the ratio of 1: 2.5: soil: water (Jackson, 1973). Organic carbon (OC) and cation exchange capacity (CEC) have been assessed by the Walkley & Black method and mixed indicator method respectively (Jackson, 1967). Available Ca & Mg have been measured by EDTA method (Black, 1965). Available potassium has been estimated by flame photometer (Hesse, 1971). Land suitability has been evaluated on the basis of concept of land utilization types (FAO, 1976; Sys et al.,1993). With the help of GIS based AHP analysis, land suitability has been produced (Saaty, 1980).

RESULTS AND DISCUSSION

GIS based AHP Model for evaluation and management of land resources

Analysis of land suitability for thermal power plant was done by using AHP approach (Carver, 1991;Sadeghi et al., 2011). All the criteria of optimum crop production have been given suitability weight. The GIS-based multi-criteria evaluation procedures involve a set of geographically defined alternatives (e.g. area) and a set of evaluation criteria represented as map layers.



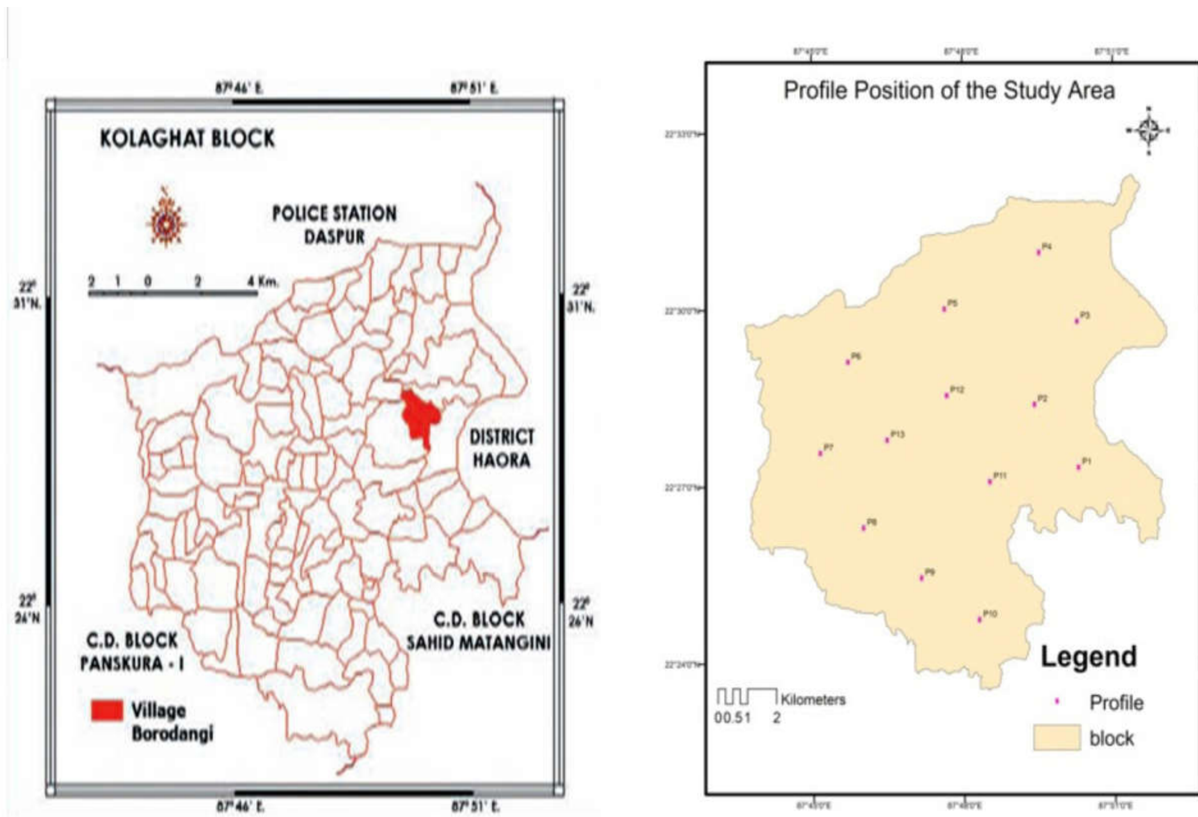


Fig. 1: Location map of Kolaghat block, district Purba Medinipur, West Bengal, India

Step 1 – Comparison the factors for land suitability

The preferences are typically expressed in terms of the weights or relative importance assigned to the evaluation criteria under consideration. The weights of relative importance directly to each attribute map layer have been assigned (Table 1-4).

Table 1: Scale of Pair-wise comparison of factors

Variables / factors	Expression of Preference of Influence
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values between adjacent scale values

Factor	Extreme Favour	Very strongly favour	Strongly favour	Slightly favour	equal	Slightly favour	Strongly favour	Very strongly favour	Extremely favour	Factor
	9	7	5	3	1	3	5	7	9	
Base Saturation										Organic carbon
Base Saturation										CEC
Base Saturation										pH

In similar manner all the factors are compared with each other and relative comparison has been stated in Table 2.

Step 2 – Pair-wise comparison and Completion of the matrix

Table 2: Pair-wise comparison and Relative comparison matrix for sesame Basic rules:

Factors	Base Saturation	Organic Carbon	Cation Exchange Capacity	pH	Soil Texture	Drainage	Flood	Slope	Average Min. Temperature	Average Max. Temperature	Relative Humidity	Rainfall
Base Saturation	1.000	0.500	0.333	0.251	1.000	1.000	5.000	5.000	3.000	3.000	2.000	0.333
Organic Carbon	2.000	1.500	3.000	3.000	3.000	3.000	3.000	3.000	2.000	2.000	3.000	0.333
Cation Exchange Capacity	3.000	0.333	1.000	1.000	1.000	3.000	3.000	3.000	3.000	3.000	2.000	0.333
pH	3.984	0.333	1.000	1.000	1.000	4.000	4.000	4.000	4.000	4.000	3.000	0.333
Soil Texture	1.000	0.333	1.000	1.000	1.000	3.000	5.000	5.000	4.000	3.000	3.000	0.333
Drainage	1.000	0.333	0.333	0.250	0.333	1.000	4.000	4.000	3.000	3.000	3.000	0.333
Flood	0.200	0.333	0.333	0.250	0.200	0.250	1.000	0.250	0.333	0.333	0.200	0.200
Slope	0.200	0.333	0.333	0.250	0.200	0.250	4.000	1.000	3.000	3.000	0.333	0.200
Average Min Temperature	0.333	0.500	0.333	0.250	0.250	0.333	3.000	0.333	1.000	1.000	3.000	0.333
Average Max Temperature	0.333	0.500	0.333	0.250	0.333	0.333	3.000	0.333	1.000	0.333	1.000	0.333
Relative Humidity	0.500	0.333	0.500	0.143	0.333	0.333	5.000	3.000	0.333	1.000	1.000	0.333
Rainfall	3.000	3.000	3.000	0.143	3.000	3.000	5.000	5.000	3.000	3.000	3.000	1.000
Total	0.955503	1.85879	1.209656	1.48651	1.26913	0.86720	0.2509	0.54151	0.527964	0.428596	0.543371	2.060854

1. If the judgment value is on the left side of 1, we put the actual judgment value.
2. If the judgment value is on the right side of 1, we put the reciprocal value.

Step 3 – Normalization & weight determination

Table 3: Determination of relative weights of the matrix for sesame

Factors	Base Saturation	Organic Carbon	Cation Exchange Capacity	pH	Soil Texture	Drainage	Flood	Slope	Average Min Temperature	Average Max. Temperature	Relative Humidity	Rainfall	Total	Relative Weight
Base Saturation	0.06042	0.06000	0.02899	0.03223	0.08584	0.05128	0.11111	0.14742	0.10843	0.11250	0.08152	0.07576	0.955503	0.079625
Organic Carbon	0.12084	0.18000	0.26087	0.38527	0.25751	0.15385	0.06667	0.08845	0.07229	0.07500	0.12228	0.07576	1.858787	0.154899
Cation Exchange Capacity	0.18126	0.04000	0.08696	0.12842	0.08584	0.15385	0.06667	0.08845	0.10843	0.11250	0.08152	0.07576	1.209656	0.100805
pH	0.24072	0.04000	0.08696	0.12842	0.08584	0.20513	0.08889	0.11794	0.14458	0.15000	0.12228	0.07576	1.486507	0.123876
Soil Texture	0.06042	0.04000	0.08696	0.12842	0.08584	0.15385	0.11111	0.14742	0.14458	0.11250	0.12228	0.07576	1.269134	0.105761
Drainage	0.06042	0.04000	0.02899	0.03211	0.02861	0.05128	0.08889	0.11794	0.10843	0.11250	0.12228	0.07576	0.867205	0.072267
Flood	0.01208	0.04000	0.02899	0.03211	0.01717	0.01282	0.02222	0.00737	0.01205	0.01250	0.00815	0.04545	0.250912	0.020909
Slope	0.01208	0.04000	0.02899	0.03211	0.01717	0.01282	0.08889	0.02948	0.10843	0.11250	0.01359	0.04545	0.541512	0.045126
Average Min Temperature	0.02014	0.06000	0.02899	0.03211	0.02146	0.01709	0.06667	0.00983	0.03614	0.03750	0.12228	0.07576	0.527964	0.043997
Average Max Temperature	0.02014	0.06000	0.02899	0.03211	0.02861	0.01709	0.06667	0.00983	0.03614	0.01250	0.04076	0.07576	0.428596	0.035716
Relative Humidity	0.03021	0.04000	0.04348	0.01835	0.02861	0.01709	0.11111	0.08845	0.01205	0.03750	0.04076	0.07576	0.543371	0.045281
Rainfall	0.18126	0.36000	0.26087	0.01835	0.25751	0.15385	0.11111	0.14742	0.10843	0.11250	0.12228	0.22727	2.060854	0.171738
Total	1	1	1	1	1	1	1	1	1	1	1	1		1

- To normalize the values, divide the cell value by its column total.
- To calculate the priority vector or weight, determine the mean value of the rows.

Table 4: Relative criterion weights or composite suitability score for multi criteria analysis of sesame

Factors	Step- I	Step-II
Base Saturation	1.1169213	14.027218
Organic Carbon	2.1503455	13.882252
Cation Exchange Capacity	1.422805	14.114474
pH	1.7644579	14.243788
Soil Texture	1.4849029	14.040158
Drainage	0.9997192	13.833672
Flood	0.2735131	13.080933
Slope	0.5886918	13.045523
Average Min. Temperature	0.5696628	12.947759
Average Max. Temperature	0.4641036	12.994168
Relative Humidity	0.6117204	13.509457
Rainfall	2.4346646	14.176635
	Total	163.89604
	Y	163.89604/12 =13.658

- Step-I: For row-2 of Table 4, Column 2-13 of row-2 of Table 3 have been multiplied by relative weight of every corresponding row of column 15 of Table 3.
- Step-II: Step-I has been divided by relative weight of every corresponding row of column 15 of Table 3.

Step 4 – Calculation of Consistency Ratio (CR)

CR = Consistency index (CI)/Random Consistency Index (RI)

CI = (Y – n)/(n – 1)

Y = Average of the products between each element of the priority vector and column totals.

Y = Sum of column 3 of Table 4 has been divided by number of factors (n=12)

CI = (Y– n)/(n – 1) = (13.658 - 12)/(12-1) = 0.15072757

CR= CI/RI= 0.15072757/1.54 = 0.097875< 0.1 (acceptable)

(RI value for n =12 has been adopted from Table 5)

The value of the random index changes with respect to the number of criteria. A value of CR less than 0.1 indicates an acceptable level of consistency in pair-wise comparisons. In other words, If CR is equal to or greater than 0.1, the weight applied on it must be reconsidered and the pair-wise matrix must bereexamined until an acceptable level is reached.

Table 5: Random Consistency Index (RI) (Saaty, 1980)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.90	1.12	1.24	1.32	1.41	1.45	1.49
n	11	12	13	14	15					
RI	1.52	1.54	1.56	1.58	1.59					

Steps 5-Aggregation of the criteria

The total score of land use suitability for one assessment unit, which is a pixel in our analysis is calculated using the following equation. S is the combined value of grid i,w_i is the weight for factor j, and x_i is the value of factor j of grid i.

$S = \Sigma w_i x_i$

Where:

S – is the composite suitability score

x_i– factor scores (cells)

w_i– weights assigned to each factor

Σ –sum of weighted factors

Applying it in GIS raster calculatorx_1, x_2, ., are also thematic layers representing the factors.

For judging crop potentiality, weighing and intensity ratings of the criteria for optimum growth of the particular crop have been adjusted. Pair-wise comparisons between the influential factors in AHP have shown the superiority of the soil chemical properties with the highest relative weight of rainfall (0171738) followed by organic carbon (0.154899) and soil pH (0.123876) for determination of sesame suitability. The lowest weight allocated to drainage is 0.020909. Consistency Ratio (CR) has been calculated and it is < 0.1 which is 0.97875 for all factors which indicates the correctness of the AHP model. After estimating the relative weights of each parameter, the influence percentage for each factor has been calculated by multiplying with 100 and scale values have been assigned as per the crop physiological requirement for optimum growth. The calculated relative weights (Table 6) have been converted to percentage and these have been used as influence % in AHP Weighted Overlay method for determination of crop suitability. Then land use suitability maps for sesame have been prepared. The result of overlapping is the reclassified crop suitability map. A suitability order has been developed by assigning numerical values on relative importance of each factor ranging from 1 to 9. After summing the overlying maps together for each level of hierarchy, a spatial comparison has been then undertaken between the crop suitability classes namely very marginally suitable (1-3), marginally suitable (4), moderately suitable (5), suitable (6) and highly suitable (7-9) and the corresponding pixels with different colour indication of land suitability indices (Table 7-9).

Table 6: Normalization and weight determination for sesame suitability

Calculated Relative weight for the crops after acceptance of CR

Factors	Base Saturation	Organic Carbon	Cation Exchange Capacity	pH	Soil Texture	Drainage	Flood	Slope	Average Min. Temperature	Average Max Temperature	Relative Humidity	Rainfall
	0.07963	0.1549	0.10081	0.12388	0.10576	0.07227	0.02091	0.04513	0.0440	0.03572	0.04528	0.17174

Table 7: Weighted overlay analysis for different crops in GIS platform

File Name	Factors/ Property	Attribute Ranges	Class	Reclassified File Name	Reclassified Class No.
idw_BS	Base saturation (%)	79-84	1	Reclass idw_BS	1
		85-90	2		2
		91-95	3		3
idw_OC	Organic carbon (%)	041-0.49	1	Reclass_idw_OC	1
		0.58-0.66	2		2
		0.67-0.74	3		3
		0.75-0.82	4		4
idw_CEC	Cation exchange capacity (meq/kg)	9.2-11	1	Reclass_idw_ CEC	1
		12-14	2		2
		15-16	3		3
		17-18	4		4
idw_pH	Soil pH	5.98-6.4	1	Reclass_idw_pH	1
		6.5-6.8	2		2
		6.9-7.2	3		3
		7.3-7.6	5		5
		7.7-8	7		7
idw_T	Texture	Sil	1	Reclass_idw_T	1
		Sicl	2		2
		cl	3		3
idw_D	Drainage	Moderate	1	Reclass_idw_D	1
		poor	2		2
idw_F	Flood	Nil	1	Reclass_idw_F	1
		Occasional	2		2
		moderate	3		3
idw_S	Slope (%)	0-1	1	Reclass_idw_S	1
		1-2	2		2
		2-3	3		3
idw_MiT	Minimum average temperature (°C)	20.2	1	Reclass_idw_ MiT	1
		20.5	2		2
		20.8	3		3
idw_MxT	Maximum average temperature (°C)	30.4	1	Reclass_idw_ MxT	1
		30.8	2		2
		31	3		3
idw_RH	Average relative humidity (%)	78.9	1	Reclass_idw_RH	1
idw_R	Average rainfall (mm)	133	1	Reclass_idw_R	1

Table 8: Preparation of weighted overlay table for sesame suitability

Raster	% Influence	Field Value						Scale Value (assigned)						Weighted Overlay Suitability File Name
Reclass_idw_BS	9	1	2	3				5	6	4				Wighte_Recl_Sesame
Reclass_idw_OC	15	1	2	3	4	5		3	4	5	6	7		
Reclass_idw_CEC	10	1	2	3	4			5	6	7	8			
Reclass_idw_pH	12	1	2	3	4	5	7	3	5	6	7	4	2	
Reclass_idw_T	12	1	2	3				5	7	6				
Reclass_idw_D	7	1	2					7	3					
Reclass_idw_F	2	1	2	3				7	4	3				
Reclass_idw_S	5	1	2	3				7	6	4				
Reclass_idw_MiT	4	1	2	3				5	5	5				
Reclass_idw_MxT	3	1	2	3				4	4	4				
Reclass_idw_RH	4	1						5						
Reclass_idw_R	17	1						6						

Table 9: Evaluated land Suitability for sesame

Land suitability	Suitability level	Evaluated no.	Total pixel counts	% of total coverage	Area in hectare
Sesame	Marginally Suitable	-	-	-	-
	Moderately Suitable	5	49930	78.32	12124.578
	Suitable	6	13820	21.68	3355.932
	Highly Suitable	-	-	-	-

In reality, sesame is cultivated in 5.21% area of total area of Kolaghat whereas GIS based AHP model suggests 21.68 % area is suitable for economic cultivation of sesame. Moderately suitable area (78.32%) for sesame needs improvement of some soil properties such as soil pH and organic carbon (Fig. 2-4).

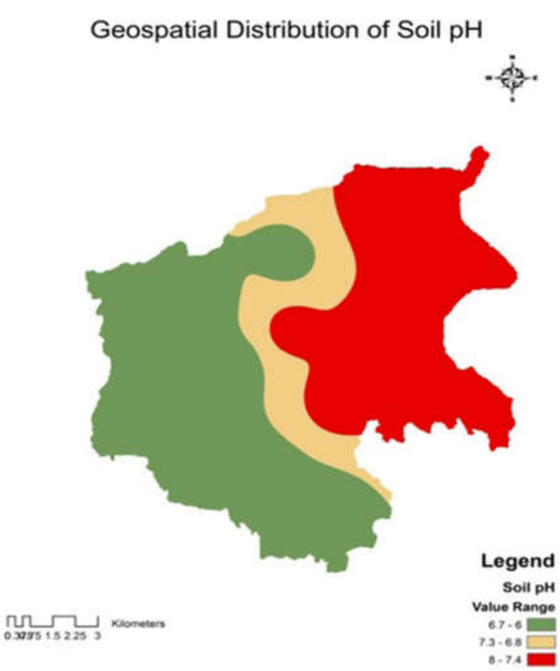


Fig. 2: Soil pH Feature Map

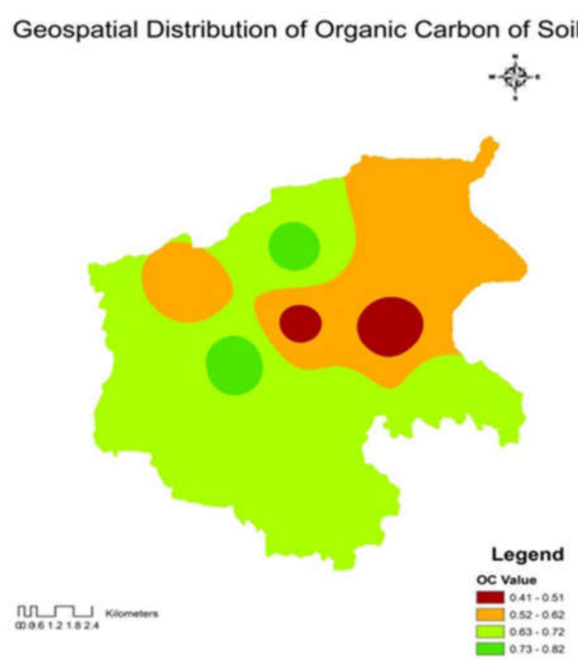


Fig. 3: Soil Organic Carbon Feature Map

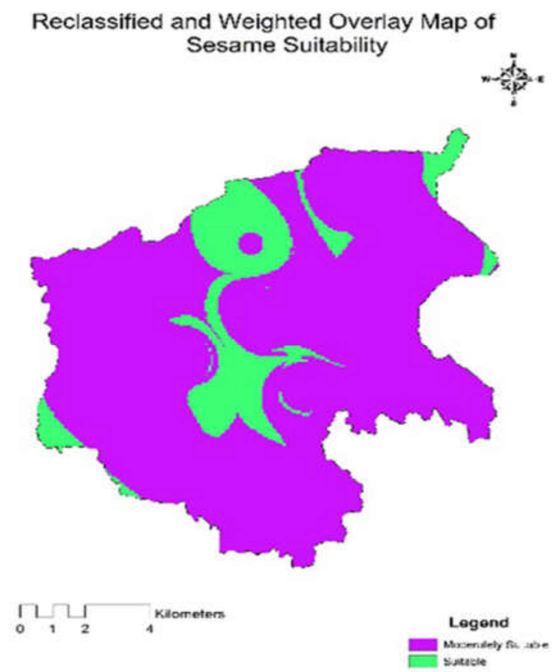


Fig. 4: Land Suitability Map for sesame

CONCLUSION

The GIS-based AHP approach in land suitability analysis is advocated technically to identify suitable land for sustainable agriculture around KTPP. This study suggests the potential crops to be grown by using land resources and supportive environment. Localized planning for the best use of land for adoption of suitable crops will be executed on the basis of the land suitability analysis. The information will be useful for future planning and technology transfer around the KTPP for agricultural sustainability.

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