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Land Suitability Evaluation for Rice (*Oryza sativa* L.) in Tirora Tehsil of Gondia District, Maharashtra - A GIS Approach

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Abstract: In the present study, land suitability evaluation has been carried out for rice in Tirora tehsil of Gondia district, Maharashtra, through analysis of landforms and soils using IRS–ID LISS-III and ancillary data Geographic Information System (GIS). Thirteen distinct landform units have been delineated in the area . The slope of the tehsil varied from level to nearly level (0-1%) to very steep slopes (>50%). The soils occurring on different land form units been studied and horizons wise soil samples were characterized and classified. The soil depth varied from very shallow (10-25 cm) to very deep (>150 cm) and soil texture ranged from clay loam to clay depending upon topographic positions. The land evaluation criterion of FAO has been followed to assess the land suitability for rice. The suitability analysis indicates that about 45.5% of total geographical area (TGA) is highly suitable, 24% is moderately suitable and 24.2% o is not suitable for rice cultivation in the tehsil.

Keywords: *GIS, Landforms, , Land suitability, Rice, Soils, Tirora*

Introduction

In order to meet the increasing demand of food for the ever growing population on the planet, crops need to be grown in areas where they are best suited. To achieve it, systematic soil resource inventory is essential and survey information need to be analyzed and integrated using the advanced tools like Geographical Information System (GIS) to assess crop suitability for different crops. Many attempts have been made in characterization of soil resources using remotely sensed data in parts of basaltic terrain (Saxena *et al.* 2000; Srivastava and Saxena, 2004; Reddy *et al.* 2013). Vishakha *et al.* (2013) establishes landform and soil relationship in a geologically complex terrain of Tirora tahsil of Gondia district, Maharashtra using remotely sensed data and GIS techniques. Maji *et al.* (2002) carried out soil resource inventory of Nagaland state of North-eastern Himalaya region. Data generated form soil survey and laboratory analysis was subsequently used to develop spatial database in GIS for soil and analysis of thematic information. Maji and Krishna (1996) described the use of GIS in soil survey and cited the capabilities of GIS, such as reclassification techniques, for thematic map generation and criterion based analysis for soil suitability evaluation.

Land suitability analysis is the pre-requisite in order to achieve higher productivity and to meet the demand for food (Kihoro *et al.* 2013). Land evaluation is a scientific procedure to assess the potential and constraints of a given land parcel for agricultural purposes (Rossiter, 1996). The analysis allows identification of the main limiting factors of crop production and enables decision makers to develop crop management system (Halder 2013). Soil qualities, based on one or more land characteristics are important for developing a suitable land use plan (FAO 1976). Eswaran *et al.* (1993) considered soil qualities like nutrient availability, effective soil volume, soil erodibility, soil depth, texture, slope condition and pH as important parameters for sustainable land use planning. The FAO (1976) framework for land suitability involves the construction of matching tables or transfer functions, and subsequent calculations of suitability. However, automating the FAO procedures, routine errors could be minimized (Davidson *et al*. 1994; Rossiter, 1990). With advances in computers processing technology, in the recent past many computer- based decision support tools and techniques have been developed in land suitability analysis (Burrough 1989; Baja *et al*. 2002; Walke *et al*. 2012).

Land suitability mapping and an analysis is one of the most useful applications of GIS for spatial planning and management (Malczewski, 2004; Bin *et al.* 2007). Zink and

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Valenzuela (1990) showed application of ILWIS software for agricultural data interpretations. Maji (1992, 1992a) carried out land evaluation for multiple land utilization types using Automated Land Evaluation Systems (ALES). Land evaluation using AGROMA software has been demonstrated by Maji *et al*. (2005). Bobade *et al*. (2010) used GIS based techniques to assess the land use suitability in Seoni District of Madhya Pradesh. Dengiz (2013) developed a spatial model for land suitability assessment for rice using GIS in Central Anatolian region of Turkey. Gangopadhyay *et al.* (2010) evaluated land resources of Peruguda micro-watershed from semi arid tropics of Ranga Reddy district of erstwhile Andhra Pradesh based on the visual interpretation of IRS-1C LISS III fused with PAN data (1:12,500 scale) and field surveys. Reddy *et al.* (2004) evaluated the land resources in a part of Eastern Maharashtra Plateau using remote sensing and GIS for cotton suitability. In the present study, an attempt has been made to evaluate the land resources of Tirora Tehsil, Gondia district, Maharashtra for rice using IRS-ID LISS III data and GIS techniques.

Geographical setting of the study area

Tirora tehsil of Gondia district is bounded by North latitudes 21° 13' 05^{11} to 21^{0} 33' 30^{11} and East longitudes 79^{0} 47' 50^{11} to 80^{0} 05' 00^{11} and is located in North Western part of the district, Maharashtra with total geographical area of 617.10 Sq.km. Climate of the study area is sub-humid, sub-tropical with well defined summer (March – May), rainy season (June – October) and mild winter (November – February). The mean annual temperature is 26.4^{0}C with a mean maximum of 29.3^{0}C and mean minimum of 24.12^{0}C. The mean annual precipitation of the tehsil is 1400 mm of which nearly 85% is received during south-west monsoon period (June-October). Wainganga river flows from north to south in the western part of the tehsil forms a major drainage system having the lower elevation ranges from 240 to 280 above MSL, whereas, the higher elevation ranges from 350 to 500 above MSL.

Material and Methods

In the present study, Geocoded IRS-ID LISS III standard False Colour Composite (FCC) of 8^{th} March 2000 (Path 100, Row 57) generated from bands 4,3 and 2 have been used in conjunction with Survey of India (SOI) topographical sheets on 1:50,000 scale for generation of base map and delineation of distinct landforms. Slope map was prepared using contour information generated from SOI toposheets and subsequently corrected based on ground truth data. The locations for representative soil profiles were identified in each landform unit. Soil profiles were studied for morphometric characteristics and horizon-wise soil samples (processed one) physical and chemical characteristics following standard analytical methods (Jackson 1973). Soils were classified according to Soil Taxonomy (Soil Survey Staff 1999). Spatial database in GIS pertaining to length of growing period (LGP), slope, soil drainage, soil depth, particle-size classes, pH status, salinity and surface stoniness have been generated following standard procedure in GIS to use in land suitability analysis.

Land Suitability Evaluation Using GIS

In AGROMA GIS software, the processes / suitability - mapping option was selected and model was built to evaluate the land resources for rice. The classes in layer were distinguished based on their characteristics for rice crop. In land suitability evaluation, the software allows to combine the thematic area, quadtrees and raster in the model. Knowledge based scores were assigned for input thematic layers in GIS based crop suitability model to define their suitability or lack thereof. Scores to the classes were assigned to represent an assessment of relative suitability. A weightage is a value that defines the relative importance of the parameter in the analysis and final output. The higher the weightage value, the more influence the associated parameter will exert in analysis. Suitability mapping will allow ranking this variable with greater importance than other variables. Based on the relative importance of the class in each layer, the relative suitability class was assigned through suitability ranking scheme (Tables 3 and 4). AGROMA GIS uses the following relative scale to classify an area's suitability for agriculture *ie,.* highly suitable, moderately suitable, marginally suitable, negligible suitability, and not suitable.

Initially ranks have been assigned for each class in the input layers. After suitability ranking was completed for each class in input layer, the suitability weightages were assigned to the layers considered. Based on the knowledge-based criteria, higher weightage was assigned to the thematic data layer of significant influence on land suitability for rice than the others. For example, soil depth, slope and LGP are the most crucial factors for rice cultivation. Hence, these layers were assigned a higher weightage than other input layers. The suitability weightages are displayed with a default weighting system and AGROMA GIS uses the number 100 divided by the number of input layers to arrive at an identical default weight for each input. To start defining the derived weightage scheme of a thematic layer, new weightage values are assigned. The total of all suitability weights must be equal to 100. After assigning the weights for layers and classes, the crop suitability model was executed in GIS and the cumulative value obtained in the model were categorized into highly suitable, moderately suitable, marginally suitable, negligible suitability and not suitable for rice cultivation.

Results and Discussion

Soil site characteristics

The geomorphic analysis reveals that the majority areas of the tehsil is under level to nearly level slopes (0-1%) and are associated with shallow, moderate and deeply weathered pediments, in narrow valley and broad valley floors. The very gentle slopes (1-3%) are associated mainly with shallow and deeply weathered pediments. The shallow weathered pediments are in association with gentle slopes (3-8%). The moderate slopes (8-15%) occupy mainly the shallow and moderately weathered pediments. The moderately steep slopes (15-30%) are in association with linear ridges, isolated mounds, dissected hilltops and shallow weathered pediments (Table 1). The eastern part of the tehsil is under steep (30-50%) to very steep slopes (>50%) with dissected hills, narrow scarp slopes, linear ridges and subdued hills. The analysis of surface drainage shows that majority of the area is under well drained conditions. The study reveals that nearly 30.1% of the tehsil in the south-east and north-west parts is covered by moderately well drained soils. Well-drained soils are found in the western and eastern parts with an area of 63.8% of the tehsil. The analysis of surface texture shows that about 30.9% of the total geographical area (TGA) is covered by clay textured soils and nearly 28.9% of TGA is under clay loam soils. The sandy clay loam and sandy loam soils occupy nearly 18.7% and 15.5% of TGA, respectively.

Physical characteristics

The soils developed on isolated mounds and denuded plateau spurs are shallow (<50 cm). Upper and lower sectors of main valley-side slopes and narrow drainage floor have deep to very deep soils (>100 cm). Shallow soils are found on the upper elevated area and isolated mounds and this area poses major limitation of soil depth for cultivation of crops. Moderately deep soil is found in the eastern part of the tehsil. Deep to very deep soils are found at lower zone. Various depth classes of the area showed that 6.9% soils are very shallow (10-25 cm) to shallow (25-50 cm) , which are in association with hummocky landforms. Nearly 11.6% of area is under moderately deep (75-100 cm) and very deep soils (> 100 cm) occupying 75.4% of TGA mostly occurring on level to gently sloping lands and moderately plain regions. About 6.1% of the TGA is occupied by the water bodies in the tehsil.

The particle size distribution shows that majority of the soils have high amount of clay. (Table 1). Soils developed on shallow weathered pediments (Sk), moderately weathered pediments deeply weathered pediments and aggraded valley fills have higher clay content (49.2 to 64.2%)(Fig. 1).

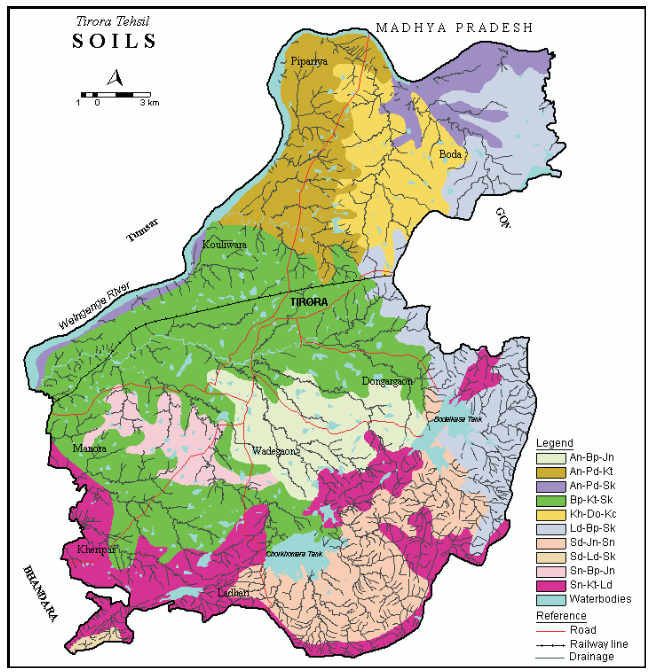

Fig.1 Soil map of Tirora tehsil

LGP ranged from high 150 to-180 days covering an area of 62.9%. very high LGP (180-210 days) and extremely high LGP (>210 days) were noticed in the northern, central and southern parts of the tehsil with an area of 16.8 and 14.2%, respectively.

chemical characteristics

The pH of the soils ranged from 4.7 to 7.7 *i.e,* moderately acidic to slightly alkaline (Table 2). The results showed that soils developed on subdued hills, moderately pediment, dissected hills and linear ridges are moderately acidic (pH 5.2) and cover 15.5% area. Soils developed on moderately weathered pediments, linear ridges, dissected hills, shallow weathered pediments, deeply weathered pediments, moderately weathered pediments,

Table 1. Physical characteristics of soils in Tirora tehsil (Weighted means)

Soil Series	Landforms	Slope %	Depth cm	Drainage	Particle Size Distribution			Texture	Water Retention		AWC mm
					Sand	Silt	Clay		33	1500	
					←	%	→		kPa		
Khmtalao	Dissected hills	30-50	25	Well drained	22.1	36.2	41.6	Clay	28.7	15.6	217
Kochi	Dissected hills and Linear ridges	15-30	50	Well drained	45.8	21.3	32.9	Sandy clay loam	18.1	8.5	161
Deori	Linear ridges	15-30	37	Well drained	37.9	22.3	39.8	Clay loam	24.8	12.5	192
Bampewada	Deeply weathered pediments	15-30	155	Well drained	22.6	27.3	50.1	Clay	30.6	17.3	252
Sonegaon	Moderately weathered pediments	1-3	115	Well drained	38.7	29.8	31.5	Clay loam	23.3	11.9	188
Lakhandure	Subdued hills	1-3	55	Well drained	45.0	16.2	39.7	Sandy clay / Clay loam	15.4	7.1	147
Karati	Shallow weathered pediments	8-15	115	Well drained	42.5	17.1	40.5	Clay	19.0	10.7	140
Jamnapur	Moderately weathered pediments	3-8	156	Well drained	27.4	23.4	49.2	Clay	32.3	17.7	247
Sakoli	Shallow weathered pediments	3-8	160	Moderately well drained	20.1	21.3	58.0	Clay	31.6	16.2	274
Paraswada	Moderately weathered pediments	8-15	135	Well drained	29.1	19.6	51.3	Clay	25.9	12.6	240
Sawarbandh	Deeply weathered pediments	1-3	151	Moderately well drained	32.8	21.3	49.2	Clay	29.1	15.8	247
Arjuni	Aggraded valley fills	0 1 -	150	Moderately well drained	15.5	22.3	64.2	Clay	36.7	22.0	285

Table 2. Chemical characteristics of soils in Tirora tehsil (Weighted means)

Soil Series	Depth (cm)	pH (1:2.5 H_2O)	EC (1:2.5 H_2O) (dSm^{-1})	Organic Carobn (%)	Exchangeable Bases Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cation exchange capacity	Base saturation (%)
					← (cmol (p^+) kg^{-1})				→	
Khmtalao	25	6.2	0.2	1.8	21.5	6.2	0.6	0.4	35.7	80.5
Kochi	50	5.2	0.2	0.6	5.4	1.5	0.2	0.1	10.5	66.5
Deori	37	5.8	0.2	0.6	10.7	4.4	0.2	0.2	17.5	87.9
Bampewada	155	6.3	0.2	0.3	14.4	7.3	0.3	0.3	27.8	80.4
Sonegaon	115	5.2	0.2	0.7	8.5	4.6	0.2	0.2	21.3	64.1
Lakhandure	55	4.7	0.2	0.7	7.2	1.1	0.2	0.2	14.2	52.6
Karati	115	6.9	0.2	0.3	19.6	4.7	0.3	0.2	27.2	91.0
Jamnapur	156	5.8	0.2	0.8	18.9	5.6	0.3	0.3	25.5	98.0
Sakoli	160	6.3	0.2	0.4	22.7	6.3	0.4	0.3	33.1	89.9
Paraswada	135	6.6	0.2	0.3	20.6	7.7	0.3	0.2	32.2	89.3
Sawarbandh	151	7.1	0.2	0.4	10.8	4.0	0.4	0.3	23.2	68.9
Arjuni	150	7.7	0.2	0.4	41.0	7.1	0.3	0.2	51.5	96.3

Table 3. Land suitability criteria for rice

Land use requirement		Rating			
Land quality	Soil-site characteristic	Highly suitable, S1	Moderately suitable, S2	Marginally suitable, S3	Not suitable, N
Temperature regime	Mean temperature in growing season (°C)	30–34	34–38	38–40	>40
LGP		>150	120-150	90-120	<90
Oxygen availability to roots	Soil drainage (class)	Imperfectly drained	moderately well drained	well drained; somewhat excessively drained	excessively drained
Nutrient availability	$CaCO_3$ in root zone (%)	<15	15 to 25	25 to 30	>30
Nutrient retention	Texture (class)	loamy	Fine loamy	fine	Loamy-skeletal
Rooting conditions	Effective soil depth (cm)	>75	51 to 75	25 to 50	<25
Soil toxicity	Salinity (EC saturation extract, dS m^{-1}) Sodicity (ESP)	Nil - Negligible	Slight	-	-
Erosion hazard	Slope (%)	0 to 3	3 to 8	8 to 15	>15

* *Flooding is considered for rainfed rice. Source: A. Natarajan (pers. communication)*

Table 4. Soil-climatic suitability criteria for rice crop

S. No.	Theme	Crop (rice)	Class	Suitability class (rice)
1	LGP	15	High (150-180)	S1
			Very high (180-210)	S1
			Extremely high >210	S1
2	Slope	15	Level to nearly level (0-1%)	S1
			Very gentle (1-3%)	S1
			Gentle (308%)	S2
			Moderate (8-15%)	S3
			Moderately steep (15-30%)	N
			Steep (30-50%)	N
			Very steep (>50%)	N
3	Land forms	10	Dissected hill top	N
			Subdued hills	N
			Linear ridge	N
			Scarp slope	N
			Isolated mounds	N
			Dissected hills	N
			Subdued plateau	S3
			S. buried pediment	S2
			Moderately buried pediment	S2
			Deeply buried pediment	S1
			Narrow valleys	S1
			Broad valley floors	S1
			Aggraded valley fills	S1
4	Soil depth	15	Shallow (25-50 cm)	S3
			Moderately deep (75-100 cm)	S2
			Very deep (>100)	S1
5	Surface drainage	10	Moderately well	S2
			Well	S3
6.	Soil texture (particle size)	10	Sandy loam	S2
			Clay loam	S1
			Sandy clay loam	S2
			Clayey	S1
7	pH	5	Moderately acidic (4.5-5.5)	S2
			Slightly acidic (5.5-6.5)	S1
			Neutral (6.5-7.5)	S2
			Slightly alkaline (7.5-8.5)	S3
8	CEC	5	10-20 cmol/kg	S3
			20-30 cmol/kg	S1
			>30 cmol/kg	S1
9	OC	10	Moderate (<0.75%)	S2
			High (0.75-1.0%)	S1
			Very high (>1.0%)	S1
10	Salinity (ECe (dS/m)	5	Nil	S1
			Slight	S2
			Strong	S3

Note: S1=Highly suitable; S2=Moderately suitable; S3=Marginally suitable; N=Not suitable shallow weathered pediments and deeply weathered pediments are slightly acidic (pH 5.5-6.5) to neutral (pH 6.5-7.5) and cover of 47.7 and 10.3%, area respectively. The soils on the aggraded valley fills are slightly alkaline (7.5-8.5) occupy about 20.4% area. The pH of the soils decreased with increasing altitude. The soils are very low in soluble salt concentration with EC values of 0.2 dSm^{-1} (Table 2) and have no salinity hazards. The organic carbon (OC) content in the soils ranged from 0.3 to 1.8% (Table 2). The soils developed on dissected hills have relatively more OC than other soils, may be due to forest cover

Cation exchange capacity (CEC) of soils varies from 10.5 to 51.5 cmol$(p^+)kg^{-1}$ (Table 2). These high values of CEC are attributed to the smectite type of clay minerals and high amount of clays. Total exchangeable bases (Ca^{2+}, Mg^{2+}, Na^+ and K^+) contributes near about 90% of CEC of these soils. Presence of these bases in sufficient quantity in the soils is favourable for plant growth. Calcium is the dominant cation followed by magnesium, sodium and potassium. It varied from 5.4 to 41.0 cmol (p^+) kg^{-1}. The dominance of Ca^{2+} may be due to basaltic parent material, which is the source of high calcium. Magnesium varide from 1.1 to 7.7 cmol (p^+) kg^{-1} (Table 2). The base saturation ranged from 52.6 to 98.0% (Table 2). .

Suitability analysis for rice

The rating and criteria used for suitability evaluation are presented in Table 3 and

The analysis for rice suitability indicates that the level to nearly level (0-1%) slopes to gentle (1-3%) slopes, very deep soils and slightly acidic soils qualifies as highly suitable' with an area of 45.52% of TGA (Fig.2 and Table 5). Gently sloping (3-8%), moderately deep soils, neutral and moderately acidic soils are moderately suitable with an area of 24.04% of TGA. The moderately sloping (8-15%), shallow and slightly alkaline soils are marginally suitable with an area of 0.12% of TGA. The moderately steep slopes (15-30%), steep slopes (30-50%), very steep slopes (>50%), dissected hills, subdued hills, scarp slopes, linear ridges soil are not suitable with 24.2% of TGA.

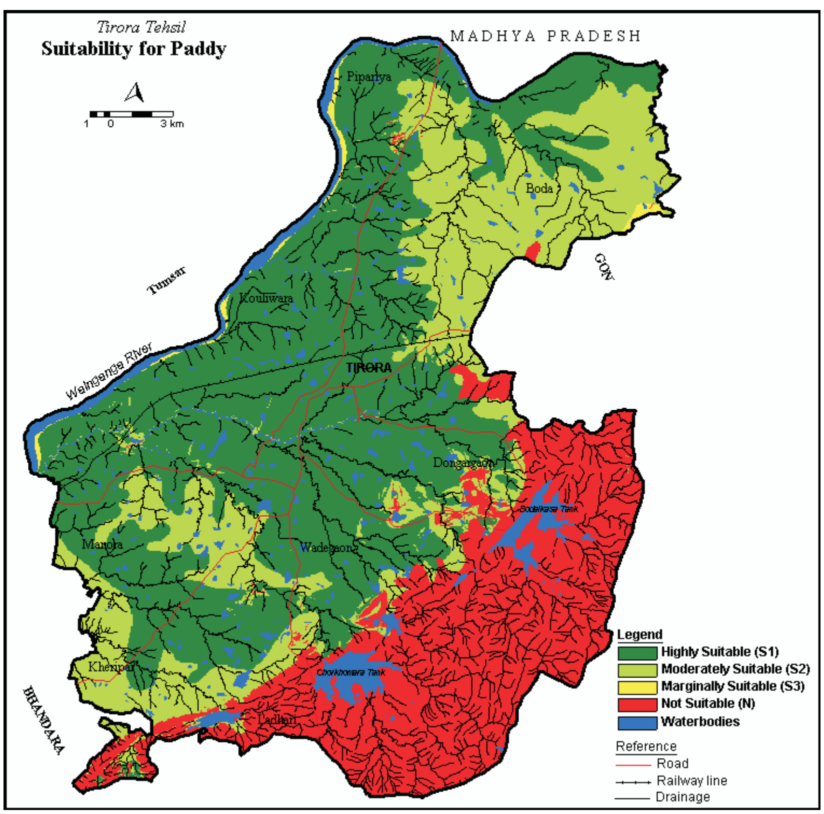

Fig.2 Rice suitability map of Tirora tehsil

Table 5. Area under different suitability for rice of the Tirora tehsil

S.No.	Suitability for rice	% Area	Area (Sq. km)
1	Highly suitable	45.52	280.90
2	Moderately suitable	24.04	148.35
3	Marginally suitable	0.12	0.75
4	Not suitable	24.23	149.52
5	Water bodies	6.09	37.58
6	Total	100.00	617.10

Conclusions

The study demonstrates the capabilities of remote sensing data in soil resource inventory and subsequent modeling in GIS for crop suitability evaluation. Integration of relevant thematic database using crop suitability modeling in GIS is of immense help to obtain better and faster results to suggest suitable land use options. Crop suitability models in GIS facilitate to combine weighted layers into a single layer depicting varying suitability of areas of interest. The study indicates that about 45.5% of TGA in the tehsil is highly suitable, 24.0% is moderately suitable and 24.2% of TGA is not suitable for rice cultivation.

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