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Geospatial assessment of soil and land properties for mango suitability in Chandanhalli sub watershed using analytical hierarchic process

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Abstract

Sustainable enhancement of productivity of a land can be achieved by bringing together crops suitable to the potentials of that land. Land resource inventory (LRI) of Chandanhalli sub watershed (5328.00 ha) falling in Bidar District of North Karnataka, India was conducted on cadastral base map at 1:7920 scale. 514 surface and 102 profile soil samples were collected and physical and chemical properties were analysed. Assessment of surface and sub-surface properties of land was done with an objective to find out status of site specific suitability of land for Mango crop in the sub-watershed. The data obtained through LRI was processed and interpreted through “Analytic Hierarchy Process (AHP)”. The results revealed that among different properties of soil and land, the weight of the soil depth was highest (30.00%) followed by soil texture (15.00%), slope (13.00%), OC (18.00%), EC (6.00%) and pH (18%). The CR was less than 0.10, the matrix had a reasonable consistency hence proved. The model revealed that, out of total area of sub-watershed, 293.0 ha (5.50%) was found highly suitable (S1), 1584.0 ha (29.73%) was judged as moderately suitable (S2), 3081.0 ha (57.83%) area was found to be marginally suitable (S3) for cultivation of mango crop. An area of 22.0 ha (0.41%) was identified as not suitable (N). Findings of this research can be extrapolated to the sub watershed of similar conditions in developing a decision support system for assessing site specific crop suitability based on potentials and limitations of soil and land properties for enhancement of land productivity.

Keywords: Land Resource Inventory (LRI), Analytic Hierarchy Process (AHP), geospatial technique-weighted overlay analysis, soil site suitability, mango

1. Introduction

Soil and land resources are declining both in quantitative and qualitative terms at a rapid rate worldwide primarily due to anthropogenic activities and secondly because of natural reasons. The pressure of producing more and more food on these limited resources to satisfy the demands of increasing world population has further aggravated the situation at alarming speed. Impact of climate change has also imposed unpredictable conditions in soil and land for cultivation of crop. Interventions like suitable soil and water conservation methods, nutrient management practices and adoption of crops based on soil and land properties can bring major positive change in productive potential of land. Each parcel of land has got its own potentials and limitations with respect to their physical, chemical and biological properties to support crop growth. Therefore to strengthen the decision support system of sustainable enhancement of productivity, site specific crop suitability is an important pre-requisite. Intensive data on inherent properties of site specific nature, influence on each other's potential and capabilities (Greenland *et al.*, 1998; Richardson *et al.*, 2023) ^[7, 11] which plays vital role in evaluating land suitability for different crops there by becomes critical inputs in making strategies for increasing productivity (Pramanik 2016) ^[10] and making agriculture sustainable (El Baroudy 2016; Falasca *et al.*, 2012) ^[4, 5].

Chandanhalli sub watershed, covering an area of 5328.00 ha, was identified as study area where, mango is one among the commonly cultivated crop. With an objective to bring out site specific crop suitability plan for mango, a detailed Land Resource Inventory (LRI) was carried out to

characterise surface and subsurface properties of soil and land. The outcomes of LRI were processed through AHP to develop site specific mango suitability map using GIS.

2. Materials and Methods

2.1 Study Area

Chandanhalli Subwatershed is located between 17°52'32.72" to

17°53' 23.164" N latitude and 77°6'58.283" to 77°6'57.47" E longitude in Humnabad taluk of Bidar district, covering an area about 5328.00 ha. (Figure1). The sub watershed comprise of 8 micro-watersheds coming under north-eastern transition zone with average annual rainfall of 847 mm. Soils of SWS are lateritic with undulating physiography.

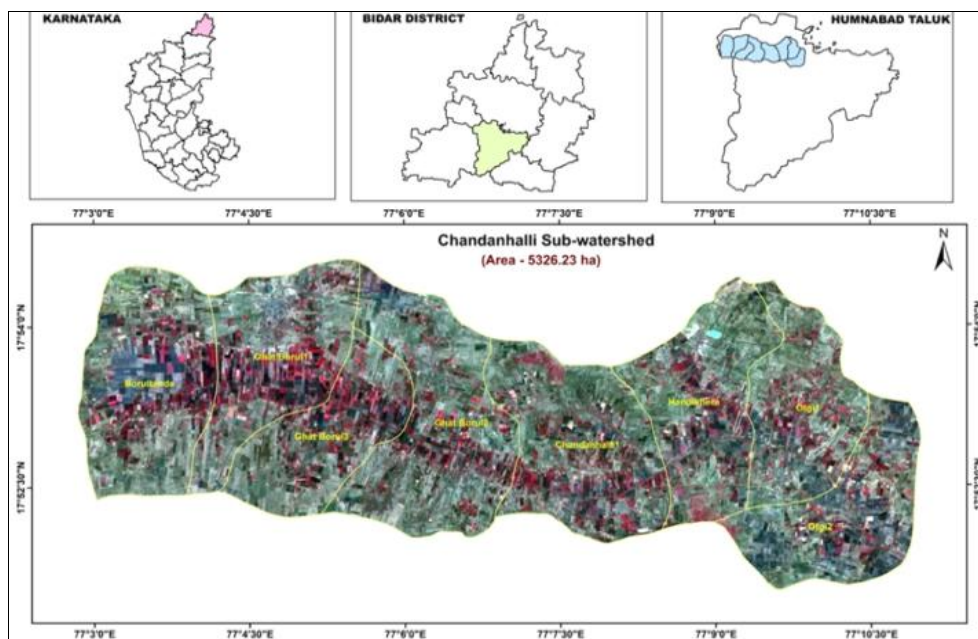


Fig 1: Location Map of Chandanhalli Sub watershed.

2.2 Criteria selection

Criteria considered for assessment of mango suitability in the study area was done by referring to manual soil site suitability criteria for major crops (Naidu *et al.*, 2006) [8]. The site specific physical and chemical properties like soil texture, depth, slope, pH, EC, and OC were recorded and used for assessing the land suitable for mango cultivation. GIS raster datasets on each of these indicators were acquired and processed from several sources for the study area. Table 1 presents the data sources used in study.

Table 1: Data sources

Sensor	Resolution (m)	Swath Width (km)	Spectral Bands(μm)
SOI (Toposheet)	1:50,000 scale	-	-
LISS-VI	5.8 m	24-50 km	0.5-0.59(Green)
			0.62-0.68 (Red)
			0.77-0.86 (near IR)
Cartosat 1	2.5m	Pan-F 30 km	0.5-0.85(Panchromatic)
		Pan-A 25 km	

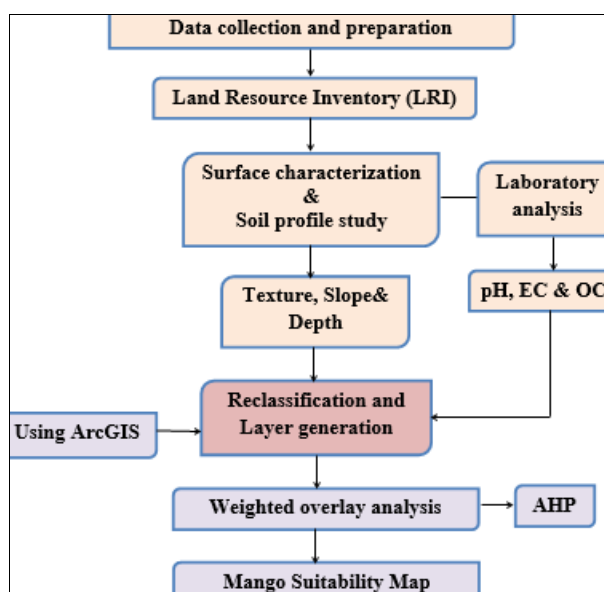


Fig 2: Flow chart of methodology

2.3 Standardization of criteria layers

All the criteria considered for cropland suitability analysis were standardized based on the soil classification and characterization guide for agricultural suitability by FAO and other guidelines defining natural and artificial constraints for agriculture suitability (Naidu *et al.*, 2006) [8]. The crop requirements were matched with the soil and land characteristics to arrive at the crop suitability. The land suitability classification for different crops, viz., two orders were recognized, order S-Suitable and order N-Not suitable. Further, the orders have classes, sub-

classes and units. Order-S has three classes, Class S1-Highly Suitable, Class S2-Moderately Suitable and Class S3-Marginally Suitable, N-Not suitable. There are no sub-classes within the class S1 as they will have very minor or no limitations for crop growth. Geostatistical interpolation technique kriging was applied to obtain the spatial layers of soil chemical properties. All these layers were classified and thematic maps were prepared as per the standards given by National Bureau of Soil Survey and Land Use Planning. These criteria maps are as shown in figure 3 and 4.

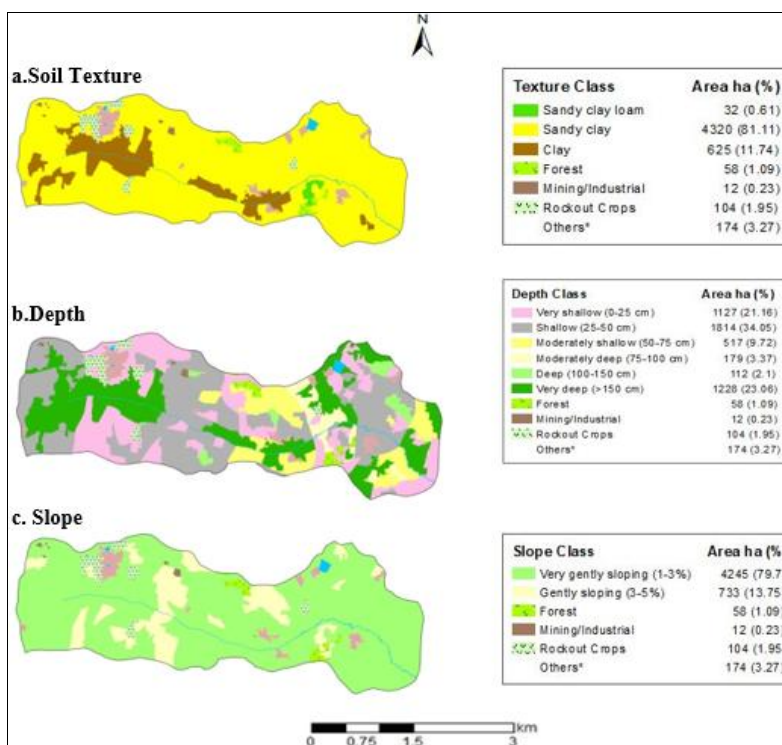


Fig 3: Criteria layers: Soil Texture, Depth and Slope

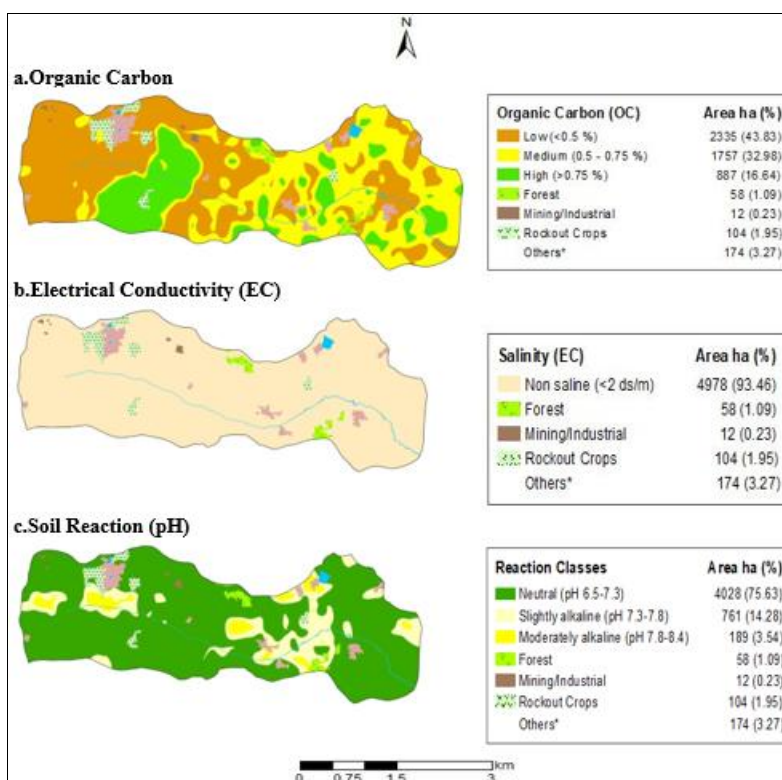


Fig 4: Criteria layers: Slope, Organic Carbon (OC), Electrical Conductivity (EC) and Soil Reaction pH

2.4 Analytical Hierarchy Process (AHP)

The relative importance values were determined following Storie index (O'geen, 2008) ^[9], where a Saaty's scale score of 1 to 9 of the respective importance were obtained. A pair wise comparison matrix is derived using Storie rating method of 9 point importance scale based on thematic and fertility layers used for soil and land suitability for mango. To obtain the weighted super matrix, each column of the super matrix is weighted by multiplying the corresponding weights and normalized. The AHP captures the idea of uncertainty in judgments through the principal Eigen value and the consistency index (CI) (Saaty, 2004) ^[12]. Consistency Index (CI) as deviation or degree of consistency was derived using the following below

equation,

$$CI = (\lambda_{max} - n) / (n - 1)$$

Where λ_{max} is the largest Eigen value of the pair-wise comparison matrix and n is the number of classes (Alonso *et al.*, 2006) ^[3].

Consistency Ratio (CR) is a measure of consistency of pair wise comparison matrix and is given by equation, $CR = CI / RI$

Where, RI is the ratio Index. The value of RI for different n values is given in. When CR value is less than 0.10, the matrix indicates a reasonable consistency. The calculated results of weight would be accepted when the consistency ratio was satisfactory.

Table 2: Random inconsistency indices (RI) for N=18 (Alonso *et al.*, 2006) ^[3]

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.46	1.49	1.52	1.54	1.56	1.58	1.59	1.597	1.609	1.618

2.5 Weighted Overlay Analysis

Thematic layers of different surface and sub-surface characters with their respective ratings were analysed through AHP (Agarwal *et al.*, 2013) ^[1] method to get their weightages. The analytical hierarchy process is a multi-attribute land evaluation technique which allows to determine the weights of these

multiple and heterogeneous criteria indicating relative importance. Different thematic layers identified in the study with their respective weightages were further integrated with each other in ArcGIS 10.6.1 software as per weighted overlay technique using the spatial analyst tool (Table 3).

Table 3: Criteria with their classes Ranks, Weightages

Criteria	Classes	Ranks	Weightages in%	Weightages in%
Soil Texture	Sandy clay loam	9	6.618	15%
	Sandy clay	7	5.147	
	Clay	5	3.676	
Soil Depth	Very shallow (0-25 cm)	4	2.941	30%
	Shallow (25-50 cm)	5	3.676	
	Moderately Shallow (50-75 cm)	6	4.412	
	Moderately Deep (75-100 cm)	8	5.882	
	Deep (100-150)	9	6.618	
	Very deep (>150 cm)	9	6.618	
Soil Slope	Very gently Sloping (1-3%)	9	6.618	13%
	Gently sloping (3-5%)	8	5.882	
Organic Carbon	High (<0.5)	9	6.618	18%
	Medium (0.5-0.75)	8	5.882	
	Low (>0.75)	7	5.147	
EC	Non saline	9	6.618	6%
pH	Neutral (6.5-7.3)	9	6.618	18%
	Slightly alkaline (7.3-7.8)	8	5.882	
	Moderately alkaline (7.8-8.3)	7	5.147	

3. Results and Discussion

Physical and chemical properties of soil of an area are the important attributes which enable to assess the land suitable for different crops. To find out the site specific suitability for mango, soil and land properties criteria like soil depth, texture, slope, organic carbon, electrical conductivity (EC) and pH was processed through AHP and Weighted Overlay Analysis (Table 2 and 3). The results indicate that soil depth with a weightage value above 30% is the most important factor in making land suitable for mango out of the six criteria. On the status of the remaining criteria OC & pH contribute 18%, soil texture with 15%, soil slope with 13% and EC with 6% weightage have proved their hierarchy in deciding mango suitability of the study area. As soil and land properties co-exist & highly interdependent in creating favorable or unfavorable conditions for crop growth, Status of soil and land characters have clearly proved their ability to become suitable or not suitable for mango crop. Based on the outcomes of the weighted overlay evaluation.

The study area of 5328.00 ha falling under four different mango suitability categories as mentioned in table 4.

Table 4: Land suitability class for mango and its distribution in chandanhalli SWS

Sl. No.	Suitability classes	Area ha	Area percentage
1.	Highly suitable (S1)	293	5.50
2.	Moderately suitable (S2)	1584	29.73
3.	Marginally suitable (S3)	3081	57.83
4.	Not suitable (N)	22	0.41
Other land uses			
5.	Forest	58	1.09
6.	Mining Industrial	12	0.23
7.	Rock out crops	104	1.95
8.	Others*	174	3.27

The reasons for land parcels belonging to S1 category are found strongly associated with deep to very deep soil depth where it

allows the mango crop to have deeper and wider tap root system which enables to extract nutrient and moisture from deeper horizons. As these soils are belonging to very gently sloping lands, they become less prone to soil, nutrient and moisture loss. Therefore higher status of organic carbon is matching to the others conditions like neutral pH, Sandy clay loam texture. On the contrary lands identified as not suitable (N) category can

be confirmed by existence of severe limitation like very shallow to shallow depth and existence of lithic contact layer which blocks the root penetration. As most of the soils belongs to 3-5% slope and making them susceptible for erosion, runoff losses, resulting in low organic carbon, moderately alkaline pH, and dominance of weathered parent material which leads to increase in severity of limiting factors of mango crop

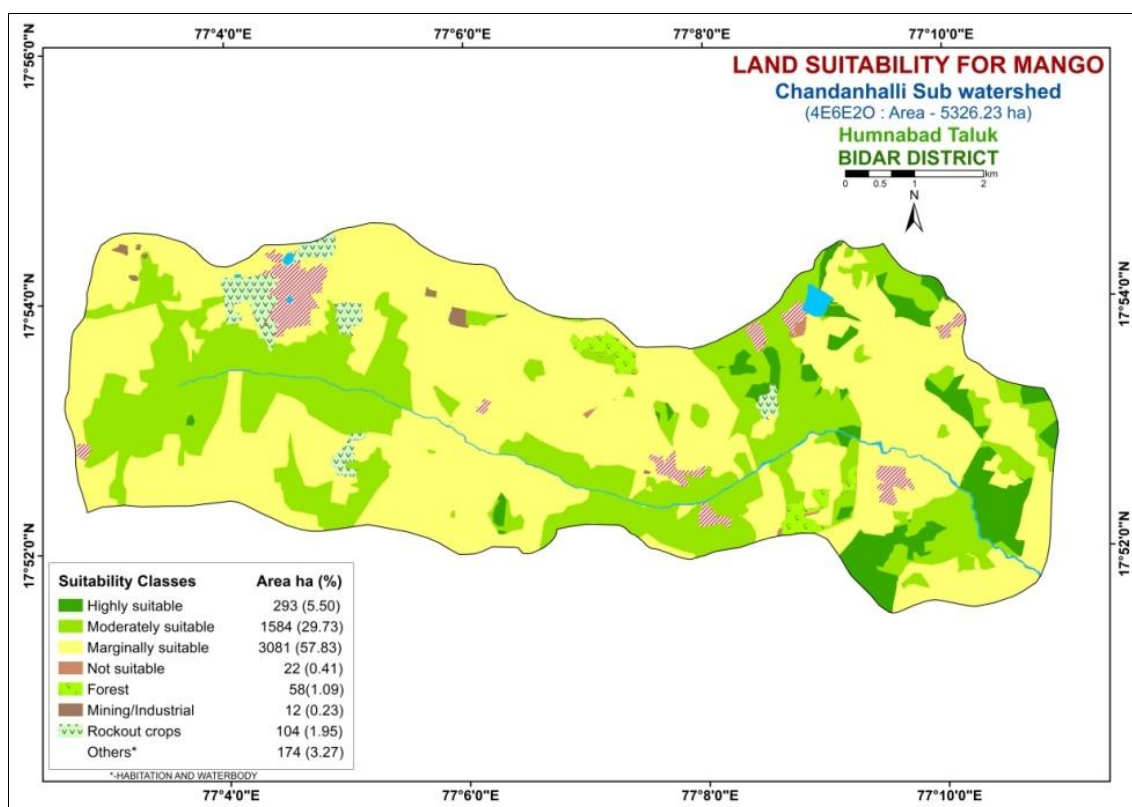


Fig 5: Land Suitability map for Mango of Chandanahalli SWS

While an area of 29.73% belonging to moderately suitable for mango in Chandanahalli SWS is in accordance with slight to moderate limitations in the form of moderately shallow soil depth leading to restrictive root penetration, drainage, moderate moisture and retention because of sandy clay texture. Large area of SWS (57.83%) has been categorised as marginally suitable with limitations like shallow soil depth which creates unfavourable conditions like restricted root penetrations, low moisture retention and poor support of land for the crop growth with gently sloping lands susceptible for erosion and loss of nutrients. These facts also coincides with low organic carbon status, moderately alkaline pH, and sandy clay texture of soil.

Conclusion

By applying weighted overlay analysis, LRI data can be used to crop specific and site specific suitability assessment. Such information can be an important input for developing decision support system model for judging crop suitability in a sub-watershed. Findings of such studies can be extrapolated and used in crop specific land-use planning for large area with similar land and soil characters.

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