



Original Research Paper

Multi-Criteria Land Suitability Analysis for Plantation in Upper Mula and Pravara Basin: Remote Sensing and GIS Approach



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Abstract

Assessment of land suitability potentials is an important step to detect the environmental limit for sustainable land management (SLM). Land suitability analysis (LSA) is more suitable, beneficial and environmentally acceptable for SLM. It deals with the assessment of land performances for the specific use like agriculture, plantation, etc. The main objective of the present study was to determine the suitable areas for plantation in the Upper Mula and Pravara Basin. GIS based Analytic Hierarchy Process (AHP) was used to analyze land suitability for plantation. Criterion like slope, LULC, depth, texture, moisture, SOC, MWHC, pH, EC and primary nutrients were used. Pairwise comparison matrix was used for calculation of weights for criterion and scores were assigned to sub-criterion using field work, experts' opinions and literature review. Weighted overlay analysis was used for final output raster map. Then cell values of raster map were divided into four classes i.e. 9, 7, 4 and 1. Finally, these classes have reclassified into four suitability levels according to FAO. About 5% of reviewed land is highly suitable, 23% moderately suitable, 14% marginally suitable and 58% not suitable for plantation in the region.

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1 INTRODUCTION

Land is reasonably stable or predictably cyclic part of the earth surface includes relief, soils, near surface rocks, minerals, flowing water, groundwater, atmospheric elements (i.e. temperature, rainfall, etc.), plants, animals, micro-organisms as well as manmade aspects like land use, settlements, industries, agriculture, etc. (FAO, 1976; Bhagat, 2012). Land regulates different cycles like carbon, nitrogen, oxygen, water, nutrients, etc. and surface systems like ecosystems, river systems, etc. (FAO, 1995). It is potential source of natural resources like soil, water, nutrients, minerals, etc. for environmental activities (Bhagat, 2013). Variations in distributions of land elements determine its suitability for agriculture, plantation, recreation, settlement, industry, watershed management, etc.

However, land elements are overused and exploited to meet their growing needs of population across the world (Feizizadeh and Blaschke, 2013). Many lands are facing different problems like soil erosion, losses of fertile soil, water logging, groundwater depletion, increase in surface run off, productivity losses, etc. (Barah, 2010). Subsistence farming practices, excessive irrigation, shifting cultivation, grazing animals, climatic hazards (floods, landslides and droughts), deforestation, etc. are reported causes of land degradation. Indian Council of Agricultural Research (2010) has reported that about 120.40 million hectares land in India is affected by land degradations i.e. water and wind erosion (94.87 million ha), water logging (0.91 million ha), soil alkalinity (3.71 million ha), soil acidity (17.93 million ha), soil salinity

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(2.73 million ha) and mining and industrial waste (0.26 million ha) waste (0.26 million ha) with annual soil losses of about 5.3 billion tones. Consequently, area under non-agricultural uses is increased by 11% in last decade whereas cultivable land and net sown area (NSA) declined by 0.8% and 0.7 %, respectively. Further, FAO has reported that approximately, 1.68% of total arable land is decreased and 47% land is undergoing degradation in last two decades. Approximately, 250 million people are directly affected by land degradation (UNCCD) and 1 billion people are at risk (WMO, 2005). About 852 million (14.9%) people of developing countries suffer from hunger and malnutrition (FAO, 2012) and 40,000 people dying per day due to nutrients' deficiency (Speth, 1993). About 22% (217 million) of the population in India is undernourished and 36% (255 million) population do not secured for food (FAO, 1999). Thus, developing countries are facing problems like poverty, food insecurity and malnutrition (FAO, 2012). Agricultural development is only solution to solve the problems of hunger and malnutrition (FAO, 2012). However, land degradation is one of the serious identified problems of agriculture and plantation across the world. Therefore, sustainable land management (SLM) can solve problems of land degradation to improve agricultural productivity to meet immediate needs of growing population (Feizizadeh and Blaschke, 2012).

Many researchers, organizations and government agencies have established the framework to monitor the degraded land using techniques of SLM (Smyth *et al.*, 1993; Dumanski, 1997; Kalogirou, 2002). These methods consider environmental qualities and conflicts in formation of land use policies for precise plantation activities (Barah, 2010). LSA is one of the fundamental steps in SLM (Dumanski, 1997). Therefore, the objective of the present study was to determine the areas suitable for plantation in the Upper Mula and Pravara Basin using GIS based AHP technique. The AHP method is one of the multi-criteria decision-making (MCDM) methods which are commonly used in land suitability analysis.

Geographical Information System (GIS) based multi-criteria evolution (MCE) approach can help researchers and planners in the field of LS to improve decision making processes (Malczewski, 1999). However, MCE techniques can undertake multiple criterion in the decision making process (Yu *et al.*, 2011) to find solutions with multiple alternatives (Jankowski, 1995). GIS can provide the facility of multiple geo-spatial data analyses and more flexibility with higher precision in decisions in order to LS (Mokarram and Aminzadeh, 2010). Therefore, MCDM based AHP method has been integrated with GIS techniques in the present study.

2 STUDY AREA

The study area lies between 19°23'01.55" N to 19°37'41.59" N latitudes and 73°36'45.03" E to 73°49'52.22" E longitudes distributed in upstream areas (44296.94 ha) in Mula and Pravara basin in Western Ghats, of Akole Tahsil, Ahmednagar District (India) (Figure 1). There are major peaks i.e. Kalasubai (the highest peak in Maharashtra height 1646m), Harishchandra Garh (1424), Ajuba Dongar (1375mm), and Kombada Dongar (1030m). The ridge from Ratan Garh towards East is water divide between River Mula and Pravara. The Bhandardara dam is on River Pravara and Ambit dam on River Mula. The rainfall varies from 4935mm at Western boundary (Ghatghar) to 1478mm at Eastern border (Dhamanvan) of the region. The average maximum temperature is recorded 35°C and minimum 10.21°C. The weather is moist in monsoon season (June-September) and it becomes dry after February. Average humidity in the region is about 70%. Humidity increases with the arrival of Southwest monsoon winds.

The deep soils are distributed on foothill zones, whereas very shallow to rocky lands at steep slopes. Small patches on slopping areas also show deep cover of soil and debris. These, deep soils are covered by medium to dense deciduous and evergreen monsoon forests at places and some of them barren also. Steep slopes and rocky land have relatively less soil water holding capacity and rate of water infiltration to the sub-surface even though rainfall is high. The deep soil at foot hill zones has potentials of plantations.

3 METHODOLOGY

MCDM based AHP methods have used for spatial analysis in plantation. LSA (Figure 2) in the present study can be discussed in six steps i.e. 1) preparation of maps and data base, 2) selection of criterion, 3) ranking, 4) formation of judgements, 5) calculation of assigned ranks, 6) preparation of Normalised Pairwise Comparison Matrix (NPCM) and finally, 7) calculation of weights.

3.1 Data Collection and Integration

The spatial information regarding selected criterion i.e. slope, LULC and soil qualities like depth, texture, moisture, SOC, MWHC, pH, EC and primary nutrients were used for present LSA for plantation in this study. Satellite data has used for preparation of thematic maps i.e. LULC, soil depth and SM. The topomaps (47 E/10, 11, 14, 15) have also procured from Survey of India for preparation of slope map.

Soil samples (74) were collected from selected sites using purposive sampling method and analysed in laboratory. Field based laboratory data were also used for preparation of thematic maps like OC, MWHC, pH, EC, Nitrogen, Phosphorus and Potassium using interpolation technique in ARC GIS.

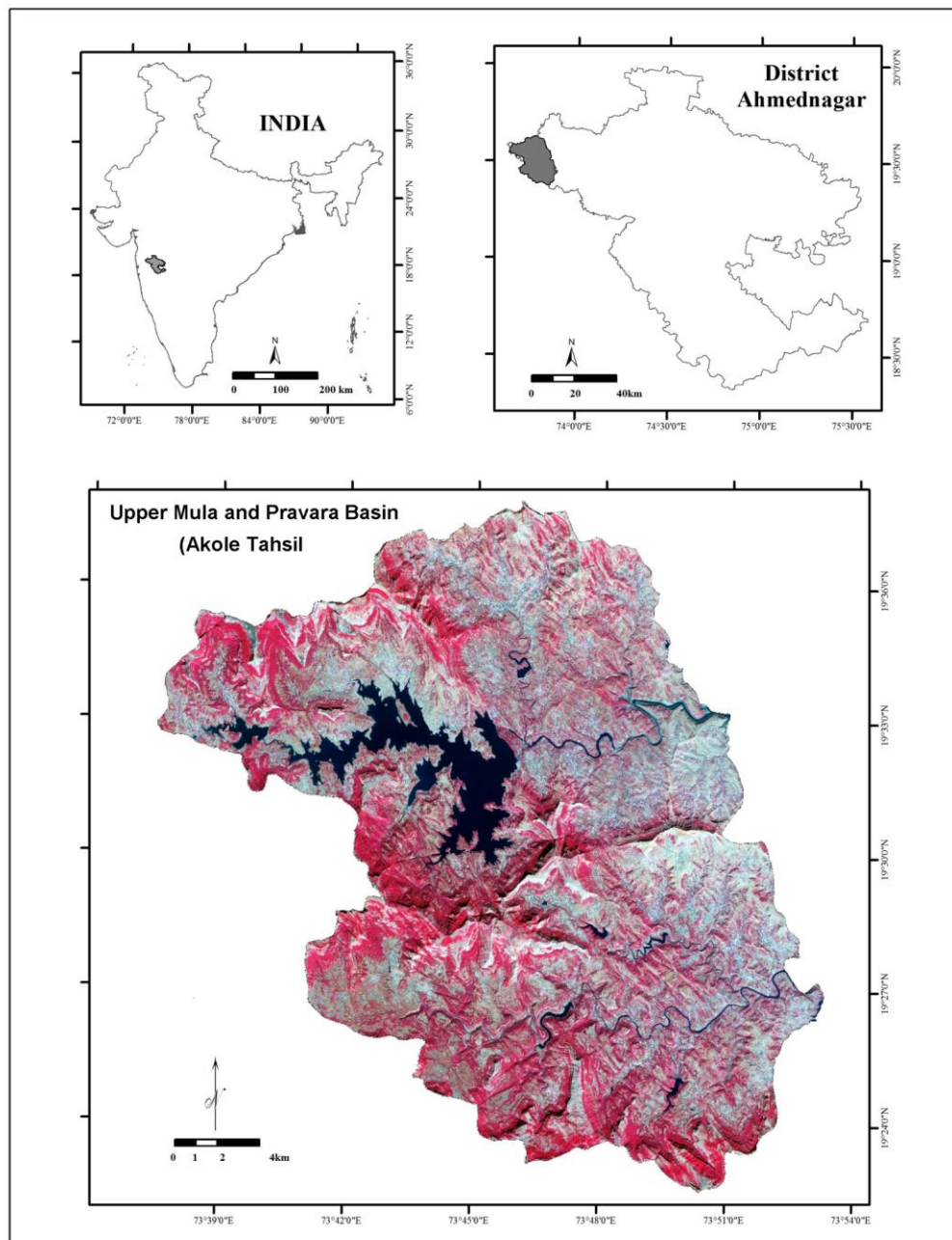


Figure 1. Study area [FCC image]

High resolution (5.8m) satellite data (cloud free) i.e. IRS P6 LISS-IV (path 095 and row 059) (21st November 2013) was procured from National Remote Sensing Centre (NRSC), Hyderabad, India and used for the spatial analysis.

The GPS [Global Positioning System] was used to locate the sites to collect soil sample and information regarding LULC and vegetation. About 158 observations distributed within suitability classes were collected for accuracy assessment.

3.2 Software and Mapping

GIS software i.e. Arc10 and ERDAS 9.2 [Earth Resource Development Application System] were used for preparation of thematic map and image analysis, respectively. Supervised classification method i.e. Bayesian maximum likelihood and collected information from field were used for LULC mapping. SM map prepared using Normalized Difference Water Index (NDWI).

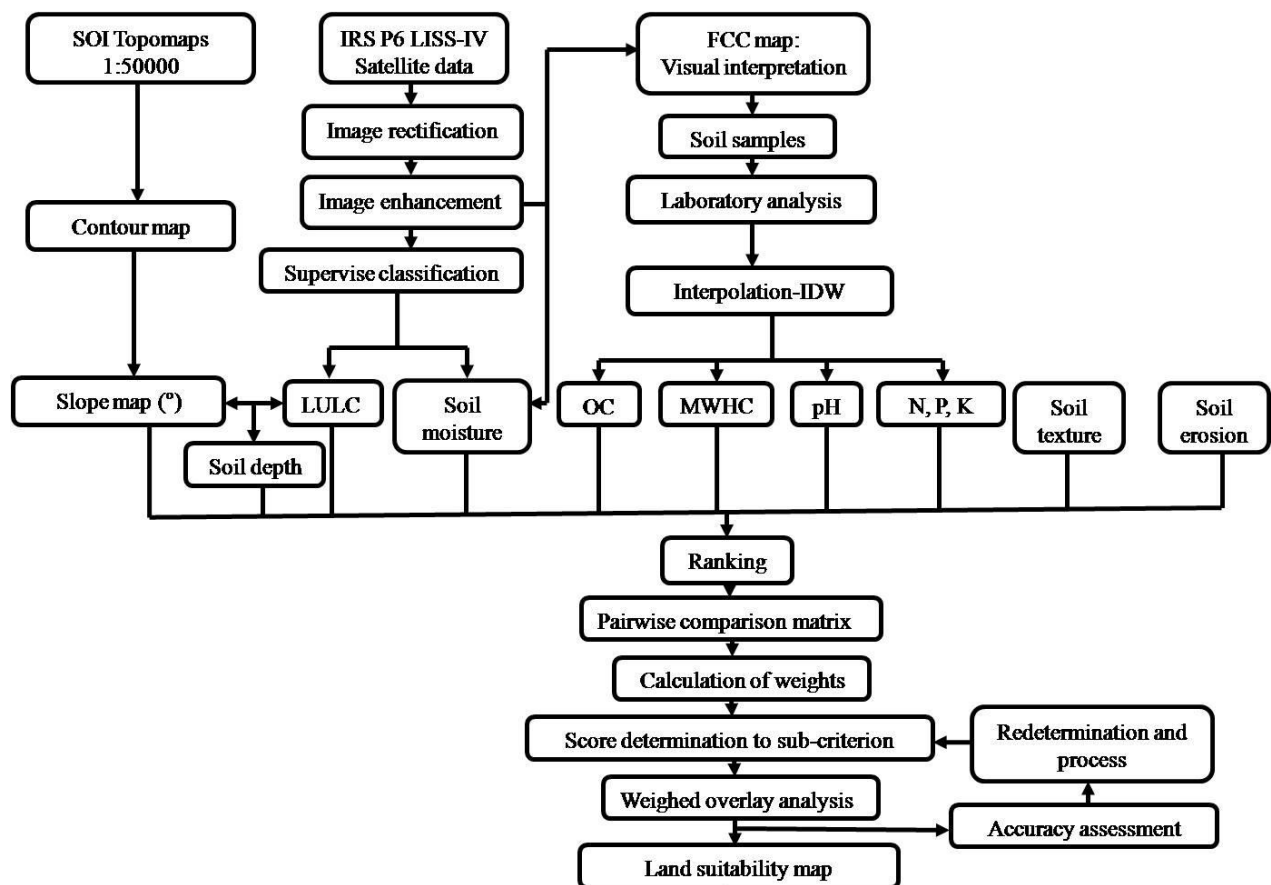


Figure 2. Methodology

3.3 Selection and Mapping the Criterion

In this study, twelve criterion such as slope, LULC and soil qualities (depth, MWHC, SOC, pH and nutrients) were selected for spatial analysis using weighted overlay analysis (WOA). Thematic maps i.e. pH, EC, OC, N, P and K were prepared using Inverse Distance Weighting (IDW) interpolation technique in GIS. Comparison for Super Decision Software (CSDS) was used for calculation of weights for selected criterion.

Experts were selected from reputed Journal (literature review) in the field of LSA for selection of criterion, assigned ranks and score of criterion. A questionnaire was made based on plantation activities and mailed to experts. These responses were loaded and analyzed in CSDS for calculation of weights of each criterion.

3.4 Analytic Hierarchy Process (AHP)

The hierarchical structure of AHP is useful for complex spatial decision with higher confidence level (Saaty, 1980). AHP technique used for LSA in this study can be outlined into six steps i.e. (1) determination of ranks, (2) pairwise comparison, (3) calculation of weights, (4) determination of score, (5) weighted overlay analysis and (6) accuracy assessment.

3.4.1 Determination of Ranks

The experts' opinions and literature review were used for assigning of ranks (1 to 12) of criterion. Lower rank indicates the most important level of criterion for plantation and higher rank indicates the least important level of parameters. Physiographic elements like slope, LULC, soil depth and soil texture have most influence on plantation and vegetation cover and assigned ranked

1-4, respectively. Soil moisture, texture, erosion and MWHC have moderate influence on plantation therefore assigned ranked 4 to 7, respectively. Zolekar and Bhagat (2015) reported that OC (rank 8), pH (rank 9), N (rank 10), P (rank 11), and K (rank 10) show comparatively insignificant relationship with plantation activities therefore higher ranks were assigned (Table 1).

3.4.2 Pairwise Comparison Matrix

The pairwise comparison matrix (PCM) was formed for determination the weights of parameters according to the AHP techniques. The judgments in the PCM (relative levels of importance of the parameters) were formed basis on experts' opinion and literature. Consistency Ratio (CR) calculates logical inconsistency of the judgments and facilitates detection of possible error. Saaty (1997) reported that a CR value up to 0.1 is acceptable for PCM judgment. CR value of the PCM judgments was calculated as zero therefore calculated weights of selected criterion are acceptable for LSA of plantation. Sub-criteria were also assigned scored within the range of 1-10, with the help of experts' opinions and literature survey (Table 2).

3.4.3 Determination of Score

Several researchers have assigned the score for sub-criterion from 1 to 10 based on land qualities, favourable conditions and limitations for plantation practices. In the present study, the scores are assigned on the basis of favourable condition for plantation, field work, experts opinion, land quality and literature survey. The higher score indicates maximum influence of sub-criteria whereas lesser score shows least suitability for plantation (Akinci *et al.*, 2013; Zolekar, 2018).

Slopes show negative relations with soil qualities and agriculture productivity (Akinci *et al.*, 2013). Therefore, maximum (10) score was assigned gentle slopes and minimum (1) to steep slopes (FAO, 1976). The 8th score was assigned to stiff slopes with deep soils and slightly eroded but less flat than gentle to moderate slopes (Bandyopadhyay *et al.*, 2009). Score, six was assigned to steep slopes (6° to 12°) with moderate deep soil and slightly undulating topography (Akinci *et al.*, 2013; Zolekar, 2016). Some patches of very steep to extra steep sloping lands (12° to 30°) show potentials of terracing but there are limitations like not easy accessible, thin soils, less SM, highly dissected and maximum percolation (Zolekar and Bhagat, 2014). These classes were classified in the class, 'marginal suitable' with score four (Table 3).

The field observations were used to assign scores to LULC classes. Lands with gentle to moderate slopes with deep soils are highly suitable for agriculture. Rice is dominant crop and major staple food to the tribal people in the region. These lands have to be kept for agriculture therefore assigned lower score (1) for agriculture in LULC. Further, about 10% lands in the region are fallow and 22% are grazing lands. The people of the region are living below poverty line. The government agencies are giving 100% financial supports to farmers of the region for horticulture to improve the income. Therefore, present analysis has been performed to detect potential lands for plantation mainly on fallow and barren lands. Deep soil is source of nutrients and minerals to plants therefore higher score (10) given to deep soil and lower score to shallow soil (4) and thin (1). Similar strategy also used for the sub-criteria of soil moisture and MWHC.

Table 1. Ranks assigned to criterion

Criterion	Slope	LULC	Depth	Texture	Soil moisture	Erosion	MWHC	OC	pH	N	P	K
Rank	1	2	3	4	5	6	7	8	9	10	11	12

Table 2. Pairwise comparison matrix

Criteria	Slope	LULC	Depth	Texture	Soil Moisture	Erosion	MWHC	SOC	pH	N	P	K	Weights
Slope	1/1	2/1	3/1	4/1	5/1	6/1	7/1	8/1	9/1	10/1	11/1	12/1	0.32
LULC	1/2	2/2	3/2	4/2	5/2	6/2	7/2	8/2	9/2	10/2	11/2	12/2	0.16
Depth	1/3	2/3	3/3	4/3	5/3	6/3	7/3	8/3	9/3	10/3	11/3	12/3	0.11
Texture	1/4	2/4	3/4	4/4	5/4	6/4	7/4	8/4	9/4	10/4	11/4	12/4	0.08
Soil moisture	1/5	2/5	3/5	4/5	5/5	6/5	7/5	8/5	9/5	10/5	11/5	12/5	0.06
Erosion	1/6	2/6	3/6	4/6	5/6	6/6	7/6	8/6	9/6	10/6	11/6	12/6	0.05
MWHC	1/7	2/7	3/7	4/7	5/7	6/7	7/7	8/7	9/7	10/7	11/7	12/7	0.05
SOC	1/8	2/8	3/8	4/8	5/8	6/8	7/8	8/8	9/8	10/8	11/8	12/8	0.04
pH	1/9	2/9	3/9	4/9	5/9	6/9	7/9	8/9	9/9	10/9	11/9	12/9	0.04
N	1/10	2/10	3/10	4/10	5/10	6/10	7/10	8/10	9/10	10/10	11/10	12/10	0.03
P	1/11	2/11	3/11	4/11	5/11	6/11	7/11	8/11	9/11	10/11	11/11	12/11	0.03

K	1/12	2/12	3/12	4/12	5/12	6/12	7/12	8/12	9/12	10/12	11/12	12/12	0.03
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Table 3. Weights and scores for plantation

Criteria	Weight	Influence (%)	Sub-criterion (with ranges)	Score for plantation
Slope (°)	0.32	32	Gentle (0-1)	10
			Moderate (1-3)	10
			Stiff (3-6)	8
			Steep (6-12)	6
			Very steep (12-20)	4
			Extra steep (20-30)	4
			Precipitous (30-90)	1
LULC	0.16	16	Agriculture	1
			Fallow land	10
			Sparse forest	7
			Scrub land	4
			Barren land	1
			Dense forest	1
			Settlement	1
			Rocky land	1
			Water body	Restricted
Depth (cm)	0.11	11	Deep soil	10
			Moderate depth	7
			Marginal depth	6
			Shallow soil	4
			Thin soil	1
Texture	0.08	8	Loam soils with moderate to gentle slope	10
			Clay loam	7
			Loam soils on steep slope	4
Soil moisture	0.06	6	Good soil moisture	1
			Medium soil moisture	7
			Less soil moisture	4
			Very less and dry soil moisture	1
Soil erosion	0.05	5	Slightly eroded	10
			Moderately eroded	7
			Highly eroded	1
Soil OC (%)	0.05	5	Highly suitable (0.61-1.00)	10
			Moderately suitable (0.40- 0.60)	7
			Marginally suitable (0.20-0.40)	5
			Not suitable (< 0.20)	1
MWHC	0.04	4	High (> 400)	10
			Moderate (200 - 400)	7
			Low (200 - 100)	4
			Very low (< 100)	1
pH	0.04	4	Highly suitable (5.00 - 7.3)	10
			Moderately suitable (7.3 - 8.0)	7
			Not suitable (> 8)	1
N (Kg/ha.)	0.03	3	Highly suitable (> 225)	10
			Moderately suitable (181 - 225)	7
			Marginally suitable (95 - 180)	4
P (Kg/ha.)	0.03	3	Moderately suitable (31 - 65)	7
			Marginally suitable (16 - 30)	4
			Not suitable (< 15)	1
K (Kg/ha.)	0.03	3	Highly suitable (> 360)	10
			Moderately suitable (181 - 360)	7
			Marginally suitable (121 - 180)	4

Some patches of the scrub lands with shallow soils are marginally suitable for plantation therefore given 4 score to its. The barren and rocky lands are not permanently not suitable for plantation activities so lower score (1) assigned. Score one is assigned to water bodies due to restricted area (Table 3). The protected dense forests are classified into the class 'not suitable'. Thus, score 1 has been assigned to agricultural lands, barren lands, dense forests, settlements and rocky lands. The score have assigned to sub-criteria of pH, OC, N, P and K basis on its content in soils.

3.4.4 Weighted Overlay Analysis

After the calculation of criterion weights and assigned scores to sub-criterion were appointed to the related layers in the Arcmap 10 environment, raster maps of 12 criterions were overlaid using the weighted overlay analysis, and land suitability map for plantation was generated. The Weighted Overlay Analysis (WOA) is a powerful tool for solving complex spatial problems in suitability analysis based on common measurement of diverse and dissimilar inputs (Kuria *et al.*, 2011). Selected raster maps were overlaid by converting their cell values to common scale, assigning a weight to each criterion and then adding weighted cell values together (Mojid *et al.*, 2009; Zolekar and Bhagat, 2015). The cell values of each input raster are multiplied by the raster's weight (Zolekar and Bhagat, 2015).

$$S = \sum_{i=1}^n W_i X_i \quad (\text{after Zolekar and Bhagat, 2015}) \quad (1)$$

where,

S : total LS score,

W_i : weight of LS criteria,

X_i : sub-criteria score of i land suitability criteria,

n : total number of land suitability criteria.

Then output raster map was generated and assigned scores were averagely calculated into four classes i.e. 9, 7, 4 and 1. Lastly, these classes were reclassified basis on FAO (1976) into the four suitability class i.e. highly suitable, moderately suitable, marginally suitable, and not suitable.

4 RESULTS AND DISCUSSIONS

The present study has been carried out based on FAO framework for land evaluation. The weights of selected criterions calculated in AHP analyses and assigned scores of sub-criterion were assigned in WOA to map the LS for plantation. LS for plantation categorised into four classes i.e. highly suitable, moderately suitable, marginally suitable and not suitable.

A. Highly suitable

Only 5 % land of reviewed area is classified into the class, 'highly suitable' for plantation (Figure 3; Table 4). These lands have gentle to moderate slopes, deep loam soils, more water retention capacities, SM and normal pH range. Nutrients i.e. N, P and K are moderately suitable and external inputs are required for plantation.

B. Moderately suitable

About 23% of reviewed lands are classified into the class, 'moderately suitable' (Figure 3). The characteristics of these lands are stiff slopes, loam soil with moderate depth, water retention capacities, SM and erosion (Table 4). The lands under grasses and very sparse forests also suggested for plantation. However, it requires additional efforts for terracing, soil and water conservation, irrigation, etc.

C. Marginally suitable

Marginally suitable lands for plantation are estimated about 14% of reviewed lands (Figure 3; Table 4). These lands have shallow soil with steep slope, less water retention capacities, SM and nutrients and more erosion activities. Terraced lands can be used for plantation but there is need of protection from intensive soil erosion.

D. Not suitable

Not suitable lands for plantation were estimated about 58% of reviewed area. These lands have precipitous slopes with rocky lands, barren lands, thin and dry soils, etc. (Figure 3). Agriculture lands and medium to dense forests are also not suggested for plantation.

5 CONCLUSION

The integrative approach of RS and GIS based MCE technique is better for LSA for plantation. The pairwise comparison matrix is used for decision makers to assign the ranks and estimation of weights of criterion. The final map of land suitability for plantation shows significant association between physical parameters like soil depth, slope, MWHC, soil texture, etc. The higher score indicates maximum influence of sub-criterion whereas lower score shows least suitability for plantation. Steep to precipitous slope, erosion degrees along with thin and shallow soil depth of the study area were most effective factors resulting permanently not suitable for plantation. Soil nutrients i.e. EC and pH are highly suitable for plantation. The nutrients like N, P and K are available at marginal to moderate level required external inputs for efficient plantation. About 5% of reviewed land is highly suitable, 23% moderately suitable, 14% marginally suitable and 58% not suitable for plantation.

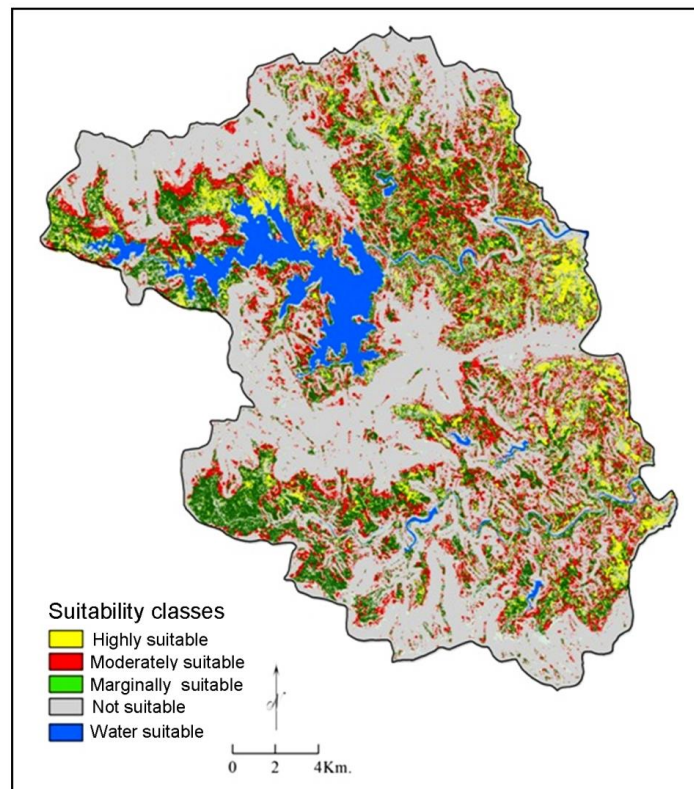


Figure 3. Land suitability classes for plantation

Table 4. Land suitability classes for plantation

Level	Area for plantation		Land characteristics/qualities	Remarks
	ha	%		
Highly suitable	2100	05	Gentle to moderate slopes with deep soils Loam texture Good water holding capacity of soils. High soil moisture pH: high to moderate (6 to 7.5) Slightly erosion Fallow land	Highly suitable land for plantation. If irrigation facilities are available.
Moderately suitable	9662	23	Stiff slopes with micro terracing Deep soils at foot hill zone (50 to 90cm) Loam texture Moderate water holding capacity of soils. Medium soil moisture pH: high to moderate (6 to 7.5) Moderate erosion Fallow land with sparse forest	Good land for plantation under proper farm management practices.
Marginally suitable	5881	14	12° to 20° slope Shallow soils (30 to 50 cm) and thin soils at a places Loam soil texture Less water holding capacity of soils Less soil moisture Availability of nutrients are low due to steep slope Terrace farming Fallow and scrub land on shallow soil and moderate slope	Medium suitability for plantation under careful management. It is possible on terrace but there is need to protections of land from intensive erosion.

CONFLICT OF INTEREST

Authors proclaimed no conflict of interest.

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ABBREVIATIONS

AHP: Analytical Hierarchy Process; **CR:** Consistency Ratio; **CSDS:** Comparison for Super Decision Software; **FAO:** Food and Agriculture Organization; **FCC:** False Colour Composite; **GIS:** Geographical Information System; **ha:** Hectare; **IDW:** Inverse Distance Weighting; **K:** Potassium; **LSA:** Land Suitability Analysis; **LULC:** Land Use / Land Cover; **MCDM:** Multiple Criteria Decision-Making; **MCE:** Multi-Criteria Evaluation; **MWHC:** Maximum Water Holding Capacity; **N:** Nitrogen; **NDWI:** Normalized Differences Water Index; **NPCM:** Normalised Pairwise Comparison Matrix; **OC:** Organic Carbon; **P:** Phosphorus; **PCM:** Pairwise Comparison Matrix; **pH:** Potential of Hydrogen; **SLM:** Sustainable Land Management; **SM:** Soil Moisture; **WOA:** Weighted Overlay Analysis.

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