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Multi-criteria land suitability analysis for agriculture in hilly zone: Remote sensing and GIS approach

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ABSTRACT

Physiographic components play a fundamental role in agriculture in hilly zone. Slope, soil depth, erosion, moisture, water holding capacities, texture and availability of nutrients have affect on agricultural production. Land suitability analysis can help to formulate the strategies for improvement in agricultural productivity. GIS based multi-criterion decision making approach using IRS P6 LISS-IV dataset was used to analyze land suitability for agriculture in hilly zone. The experts' opinions and correlation analyses were used to decide the ranks of influencing criterion whereas pairwise comparison matrix in 'Comparison for Super Decision Software' used to determine the weights. The scores for sub-parameters showing internal variations within the criteria assigned based on field work and reported norms in published literature. About 17% (7326 ha) of reviewed area are classified in the class 'highly suitable', 29% (12,372 ha) in 'moderately suitable', 16% (6514 ha) in 'marginally suitable' and 38% (15,798 ha) in 'not suitable' for agriculture. The land suitability classes i.e. 'highly suitable' and 'not suitable' in suitability map are precisely estimated than the classes 'moderately suitable' and 'marginally suitable' both in producer's and user's point of view. The methodology, techniques and findings of the study can be useful to assess the land suitability for agriculture in hilly zones.

1. Introduction

Land is reasonably stable or predictably cyclic part of the earth surface includes relief, soils, near surface rocks, minerals, flowing water, groundwater, near surface 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 elements determine its suitability for agriculture, plantation, settlements, industries, dams, watershed management, etc. However, land elements are overused and exploited. Many lands are facing different problems like soil erosion, water logging, groundwater depletion, heavy run-off, productivity losses, etc. (Barah, 2010; Zolekar and Bhagat, 2014). Degraded lands are threatening the food and energy securities, water availability and quality, biodiversity, human life, etc. (Bhagat, 2012). 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 and 16 million (1.4%) people of developed countries are suffering from hunger and malnutrition (FAO, 2012). Therefore, different studies are undertaken for land suitability analysis (LSA) and land use planning and management (Dumanski, 1997; Schwilch et al., 2011; Nyeko, 2012). LSA is one of the fundamental steps in sustainable land management (Mcdonald and Brown, 1984).

LSA is a method of detecting inherent capacities (Bandyopadhyay et al., 2009) and its potential and suitability for different purposes (FAO, 1976; Akinci et al., 2013). Land evaluation measures the degree of land appropriateness for land use based on land qualities (Hopkins, 1977; Collins et al., 2001; Malczewski, 2004) and requirements (FAO, 1976). Multi-criterion evaluation (MCE) technique is widely used for LSA. MCE of land suitability (LS) involves multiple criterion like bio-physical elements i.e. slope, relief, drainage, soil properties, atmospheric conditions, vegetation, etc. as well as socio-eco-cultural aspects in decision making process (Wang et al., 1990; Joerin et al., 2001; Yu et al., 2011; Akinci et al., 2013) to find solutions of different problems related to land with multiple alternatives (Jankowski, 1995). Geographical Information System (GIS) is useful to analyses the multiple geo-spatial data with higher flexibility and precision in

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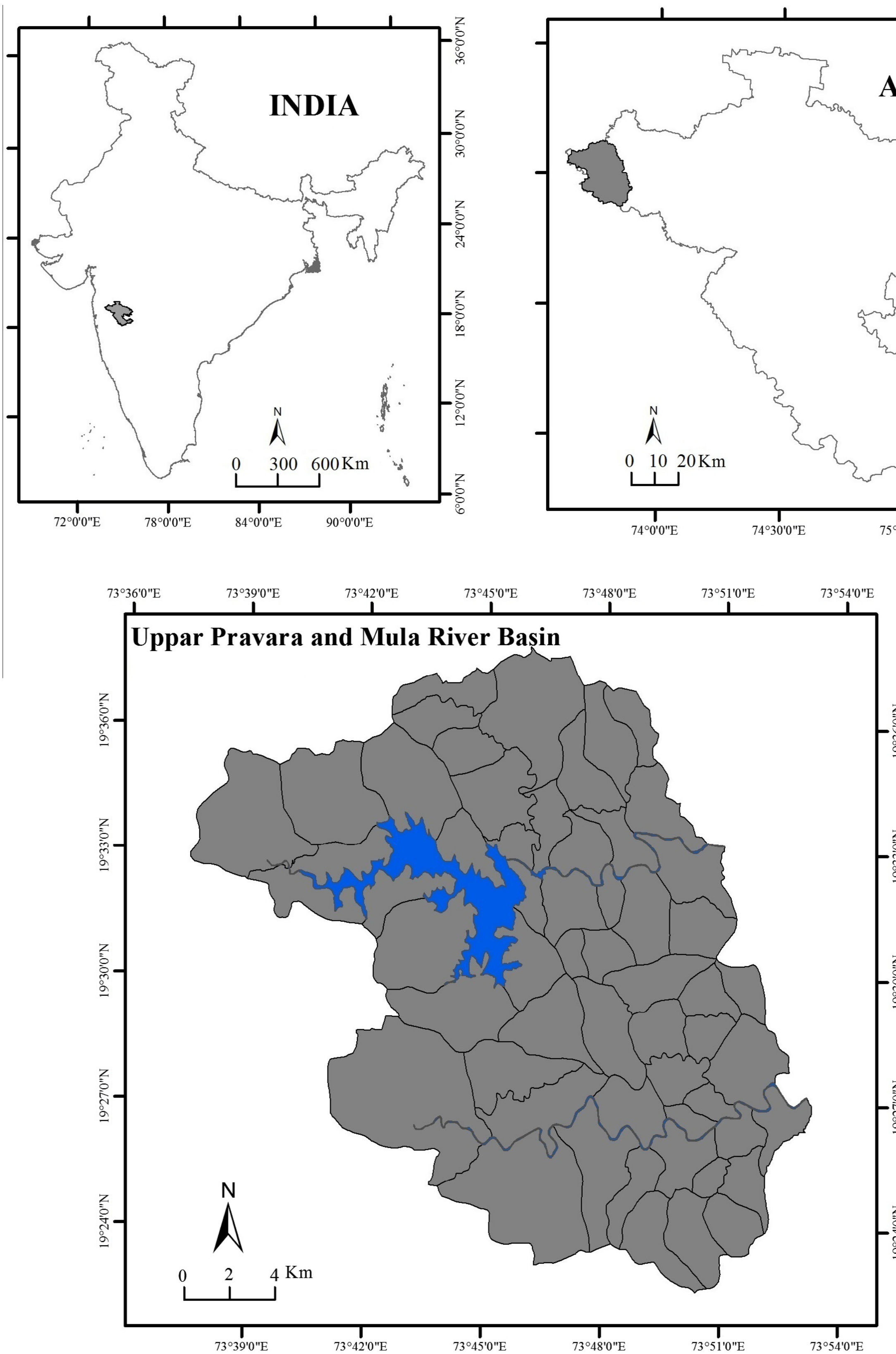

Fig. 1. The study area: upper Mula and Pravara basin.

LSA (Mokarram and Aminzadeh, 2010). Therefore, Multi-criterion Decision Making (MCDM) technique has been integrated with GIS techniques in different studies for land use decision support (Cengiz and Akbulak, 2009; Mendas and Delali, 2012) in complex problems of land management with prioritised alternatives (Malczewski, 2006). This technique widely used for LSA to detect the potential lands for agriculture (Prakash, 2003; Shalaby et al., 2006; Olayeye et al., 2008; Bandyopadhyay et al., 2009; Yu et al.,

Table 1
Techniques, data and criteria used for land suitability analysis.

Author	Techniques	Criterions	Data	Suitability field
Wang (1994)	GIS based-artificial neural networks	Slope, depth, moisture, aeration, fertility, texture, salinity, temperature and accessibility	Thematic map	Agriculture
Bojorquez-Tapia et al. (2001)	GIS-based multivariate application	Vegetation, land cover, soil type, landforms, elevation, major roads and urban areas	Land sat TM and thematic map	Land use planning
Joerin et al. (2001)	Outranking multi-criteria analysis Homogeneity index suitability index	Impacts on a nature reserve, landscape, water table, air pollution, noise, accessibility, climate, land slide, distance to localities and public facilities	Thematic map	Land use planning
Kalogirou (2002)	Boolean classification method	Soil mechanics, toxicities, slope, and flood erosion hazard, rooting condition, water level and drainage	Thematic map	Crop
Shalaby et al. (2006)	Square root and Storied method	LULC, texture, CaCo3, CaSO4, EC, ECP, organic matter, soil depth, slope and drainage	ETM+ and thematic map	Crop (Perennial)
Olayeye et al. (2008)	Index productivity	Soil depth, temperature, slope, rainfall, humidity, drainage, texture, EC, OC, pH, N, P, K and cation exchange capacity	Thematic map and field base	Rice (Irrigated low land)
Bandyopadhyay et al. (2009)	AHP	LULC, soil type, organic matter, soil depth and slope	IRS-1D LISS-III and satellite data	Agriculture
Cengiz and Akbulak (2009)	AHP	Soil depth, land-use capability class, erosion hazard, slope, elevation, distance to source of water, distance to road and limiting soil factors	Thematic maps	Land use
Jafari and Zaredar (2010)	AHP	Slope, elevation, LULC, erosion, climate, soil hydrology, soil depth, soil structure, soil texture, vegetation types and density, rainfall, temperature, distance from population centers and distance from surface water	Thematic maps	Rangeland management
Chandio et al. (2011)	AHP and WLC	Available land, land value and population density	Thematic maps	Public parks
Chandio and Matori (2011)	PCM	Accessibility, topography, LULC and economic factors	Thematic maps	Hill side development
Foshtomi et al. (2011)	Square root and Storied method	Soil depth, texture, EC, OC, pH, N, P, K and cation exchange capacity	Thematic maps	Tea plantation
Mustafa et al. (2011)	MCDM Approach	Soil depth, texture, EC, OC, pH, N, P, K, ECP and $CaCO_3$	IRS-P6 LISS III satellite data and thematic Maps	Crops
Feizizadeh and Blaschke (2012)	AHP	Elevation, slope, aspect, soil fertility, soil PH, temperature, precipitation and groundwater	SPOT 5, thematic maps	Agriculture
Akinci et al. (2013)	AHP	Soil groups, soil depth, land use, erosion, slope, aspect, elevation and soil parameters	Thematic maps and field base data	Agriculture
Garcia et al. (2014)	AHP	Accessibility, security, needs of the agricultural product warehouse, acceptance and costs	Thematic maps	Agricultural product warehouses

Table 2
Correlation matrix.

	Slope	Depth	OC	WHC	PH	N	P	K	Rice	*Varai*	*Nagali*	*Khurasani*
Slope	1											
Depth	−0.61**	1										
OC	0.01	0.03	1									
WHC	−0.64**	0.95**	−0.00	1								
PH	0.15	−0.25*	0.12	−0.28*	1							
N	−0.56**	0.82**	0.04	0.84**	−0.16	1						
P	−0.17	0.61**	0.09	0.54**	−0.03	0.40**	1					
K	0.06	0.05	0.33**	0.05	0.33**	0.03	0.30**	1				
Rice	−0.73**	0.80**	−0.04	0.79**	−0.26*	0.67**	0.31**	−0.05	1			
Varai	0.58**	−0.16	−0.10	−0.23*	−0.14	−0.24*	0.00	−0.11	−0.28*	1		
Nagali	0.60**	−0.14	−0.05	−0.19	−0.17	−0.22	0.03	−0.09	−0.30**	0.96**	1	
Khurasani	0.51**	−0.38**	0.22	−0.40**	0.16	−0.26*	−0.16	0.06	−0.45**	0.18	0.22	1

** Correlation is significant at 0.01 level (2-tailed).
* Correlation is significant at 0.05 level (2-tailed).

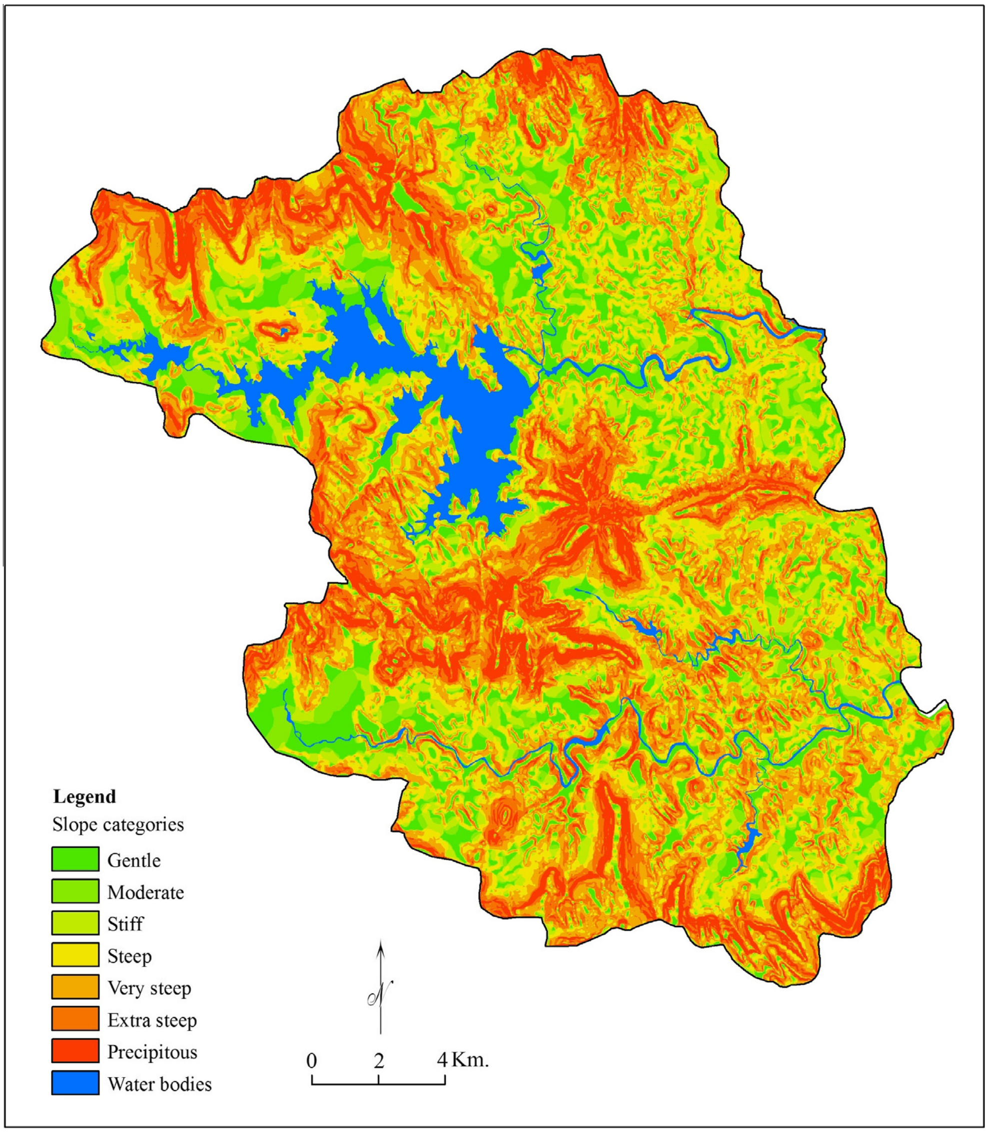

Fig. 2. Distribution of slopes.

2011; Foshtomi et al., 2011; Samanta et al., 2011; Mustafa et al., 2011; Mahabadi et al., 2012; Halder, 2013; Rabia et al., 2013), plantation (Bhagat, 2009; Zolekar and Bhagat, 2014), watershed management (Steiner et al., 2000), settlements (Soltani et al., 2012), industries (Kauko, 2006), etc.

Further, Analytical Hierarchy Process (AHP) is widely used for MCDM of LS for different use. AHP determines the weight of influence in certain land use based on pairwise comparisons of parameters according to relative importance (Miller et al., 1998; Cengiz and Akbulak, 2009). Bojorquez-Tapia et al. (2001), Joerin et al. (2001) and Kalogirou (2002) have considered expert opinions to determine the ranks and criterion for LSA. Thus, previous LSA using AHP techniques are based on criterion suggested in previous literature and experts' opinions. Further, correlation analyses give robust identification of influences criterion of LS for agriculture (Datye and Gupte, 1984). Therefore, MCE and MCDM base AHP technique was used in this exercise to detect the LS for agriculture in hilly zones using the influencing criterion suggested in expert opinions, correlation analysis and previous literature for lands in hilly zones.

Satellite data at coarse and moderate resolution i.e. TM (30 m) (Bojorquez-Tapia et al., 2001), ETM+ (28.5 m) (Shalaby et al., 2006; Golmehr, 2008), IRS-1D LISS-III (23 m) (Bandyopadhyay et al., 2009; Mustafa et al., 2011; Singh, 2012) and SPOT 5 (10 m) (Feizizadeh and Blaschke, 2012) with conventional data like field work, maps, records in government offices, laboratory analyses, etc. have been used for LSA in different studies. However, topographic characteristics i.e. slope, aspects, etc. are influencing the distribution of soil depth, soil moisture, level of soil erosion, availability of nutrients, LULC, etc. (Bandyopadhyay et al., 2009; Akinci et al., 2013). Therefore, the accuracy of results achieved in LSA is depending on variations in topographic characteristics. Fine resolution satellite data sets i.e. Quick Bird, IKONOS, IRS P6 LISS-IV, etc. are more suitable than coarse resolution data to achieve higher accuracy in results of LSA using MCDM (Zolekar and Bhagat, 2014) for LSA for agriculture especially in hilly zones. Therefore, fine resolution IRS P6 LISS-IV (5.8 m) data sets along with conventional data i.e. slope map, soil map and laboratory data were used for MCE and MCDA for LSA for agriculture in hilly zones of upper Mula

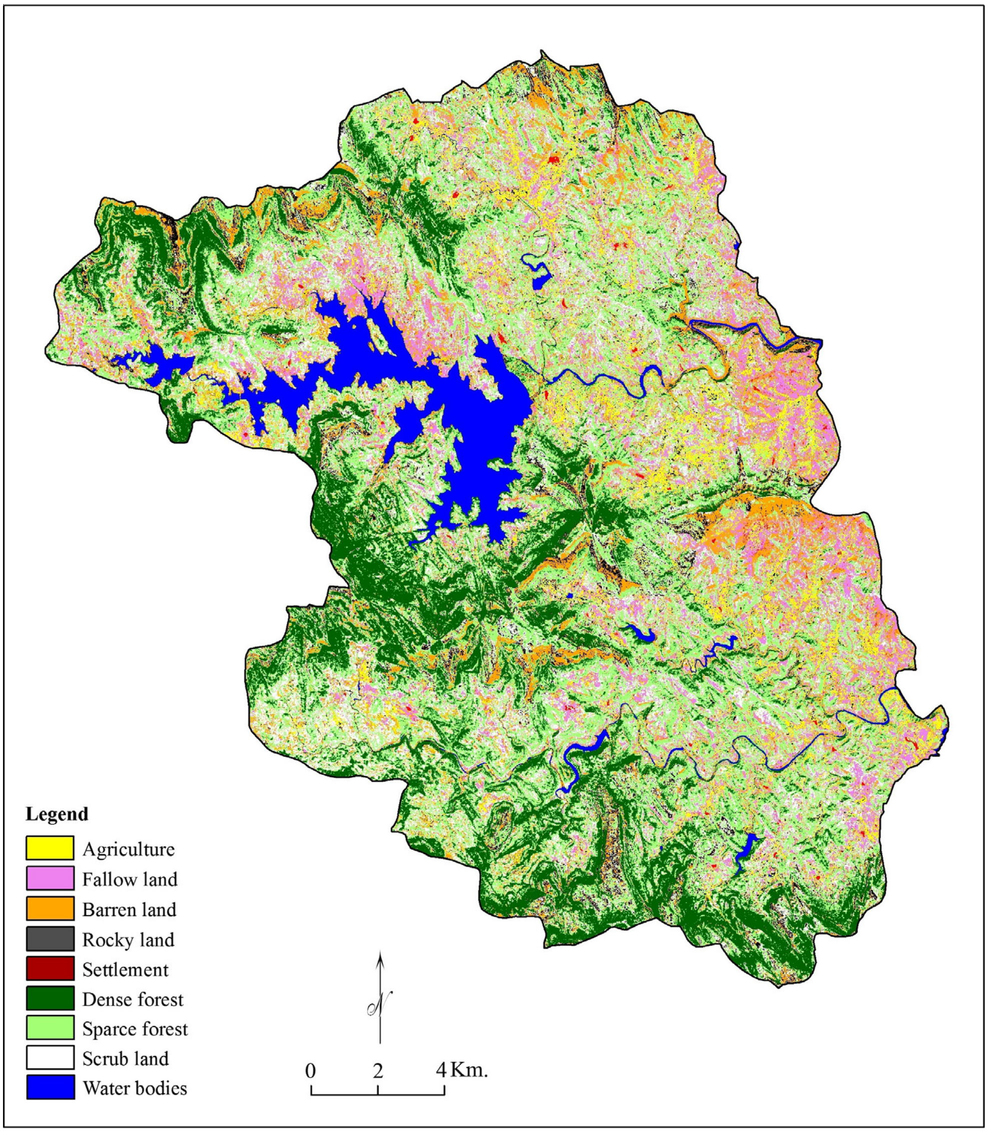

Fig. 3. Land use/land cover.

and Pravara basins. The accuracy assessment was performed to achieve better results and applicability.

2. Study area

The study area (44296.94 ha) counters the part of upstream zone in Mula and Pravara basins in Western Ghats, Maharashtra (India) (Fig. 1). Altitude varies from 1646 m to 620 m with major peaks i.e. Kalasubai (the highest peak in Maharashtra, height 1646 m), Harishchandra Garh (1424), Ajuba Dongar (1375 mm), and Kombada Dongar (1030 m). The ridge from Ratan Garh toward East is water divide between River Mula and Pravara. The Bhandardara dam is constructed on the River Pravara and Ambit dam on the River Mula. The rainfall varies from 4937 mm at Western boundary (origin of rivers) to 1904 mm at Eastern border (Randha). The deep soils are distributed on foothill zones, whereas very shallow soils with rocky patches at steep slopes. These shallow soils have very less water holding and more infiltration capacities. Small patches on slopes 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 are barren also. The deep soils at foot hill zones have potentials of agriculture and plantations. About 90.32% (Census, 2011) of the total population of the region is classified as tribal viz. *Mahadevkoli and Thakkar* with literacy of 66% population (Census, 2011). Primary economic activities i.e. agriculture, raring the livestock and gathering the minor forest products are major sources of income to the population. Rice is the major crop in the region.

3. Methodology

3.1. Data base

The spatial information regarding selected criterion i.e. slope, LULC and soil qualities like depth, texture, moisture, organic carbon (OC), MWHC, potential of hydrogen (pH), electronic conductivity (EC) and primary nutrients were used for present LSA in this study. Satellite data was used for preparation of GIS layers i.e. LULC, soil depth and soil moisture. The topomaps (47 E/10, 11, 14, 15) were used to prepare slope map whereas OC, MWHC, pH, EC, Nitrogen (N), Phosphorus (P) and Potassium (K) maps were estimated using interpolation technique and laboratory data of soil analyses.

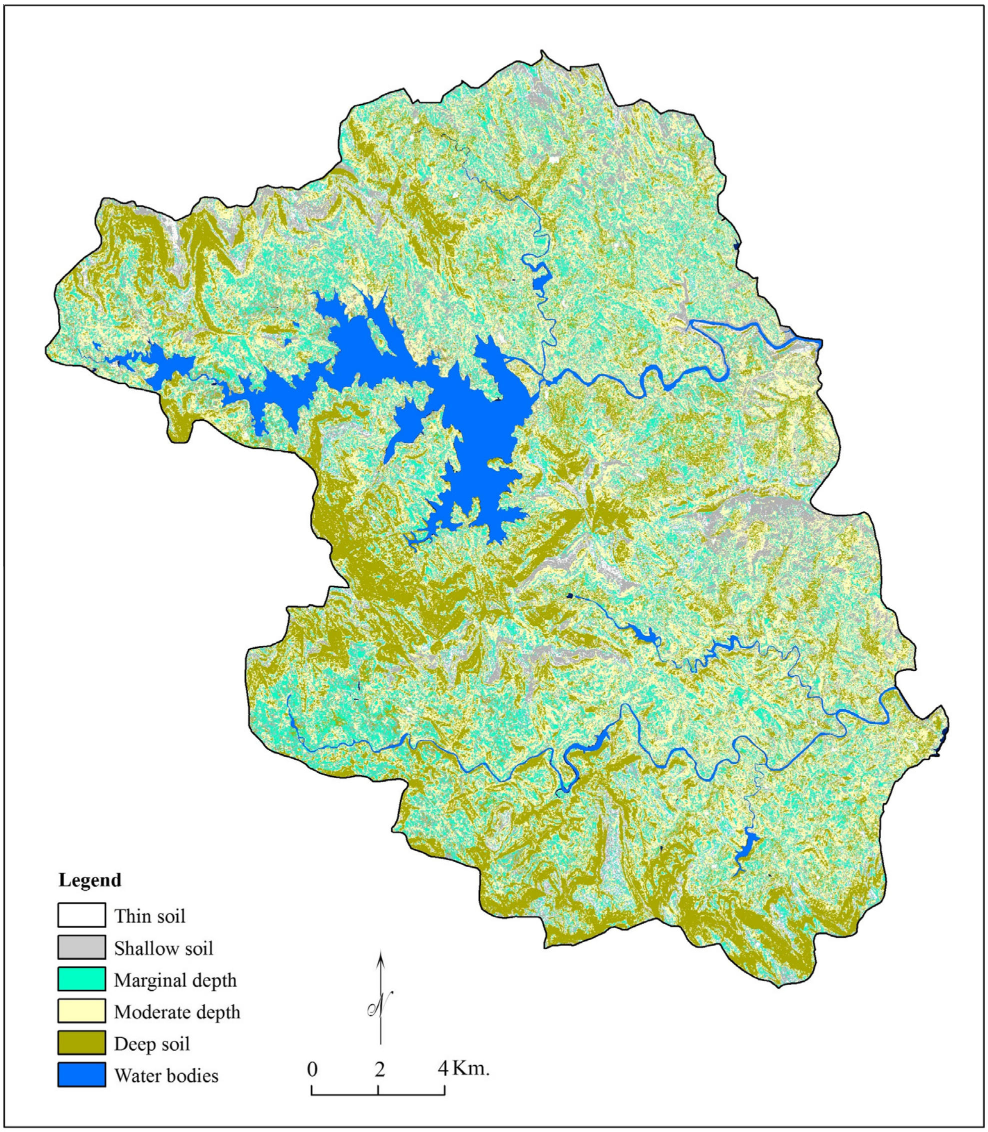

Fig. 4. Distribution of soils.

3.1.1. Satellite data

The moderate resolution satellite data i.e. TM (30 m), ETM+ (28.5 m), IRS-1D LISS-III (23 m), SPOT 5 (10 m) is widely used in LSA to detect the potential sites for agriculture, plantation, irrigation, watershed management, settlement and industries (Bojorquez-Tapia et al., 2001; Shalaby et al., 2006; Kauko, 2006; Srdjevic et al., 2007; Golmehr, 2008; Bandyopadhyay et al., 2009; Mustafa et al., 2011; Singh, 2012; Feizizadeh and Blaschke, 2012; Soltani et al., 2012). However, fine resolution satellite data like Quick Bird, IKONOS, Rapid Eye and IRS P6 LISS-IV are suggested to achieve better accuracy in LSA (Hu et al., 2013). Therefore, fine resolution (5.8 m) satellite data captured by IRS P6 LISS-IV (path 095 and row 059) (21st November 2013) in cloud free condition was procured from National Remote Sensing Centre (NRSC), Hyderabad, India and used for the analysis.

3.1.2. Field work

The field work was carried out to collect the information of LULC, cropping pattern, soil depth and crop yield. Soil samples (74) were collected from the selected sites using stratified random sampling method. The strategies for random sampling were designed based on distribution of slope, soil depth and LULC. These samples were analyzed in laboratory to detect physical i.e. MWHC and chemical properties i.e. pH, EC, OC, N, P and K.

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

3.1.3. Expert opinion

Expert opinion with GIS techniques helps to ensure realistic applicability of data sets prepared for LSA (Kalogirou, 2002; Elsheikh et al., 2013). The studies like Bojorquez-Tapia et al. (2001), Joerin et al. (2001) and Kalogirou (2002) have used expert opinions to determine the criterion, assign the ranks and calculate the weight. The eminent scholars with influenced publications of LSA were selected for expert opinions about criterion used in the study and its level of influence in land use. A questionnaire was designed based on agricultural activities in hilly zone and mailed to experts. About 21experts have responded and gave useful

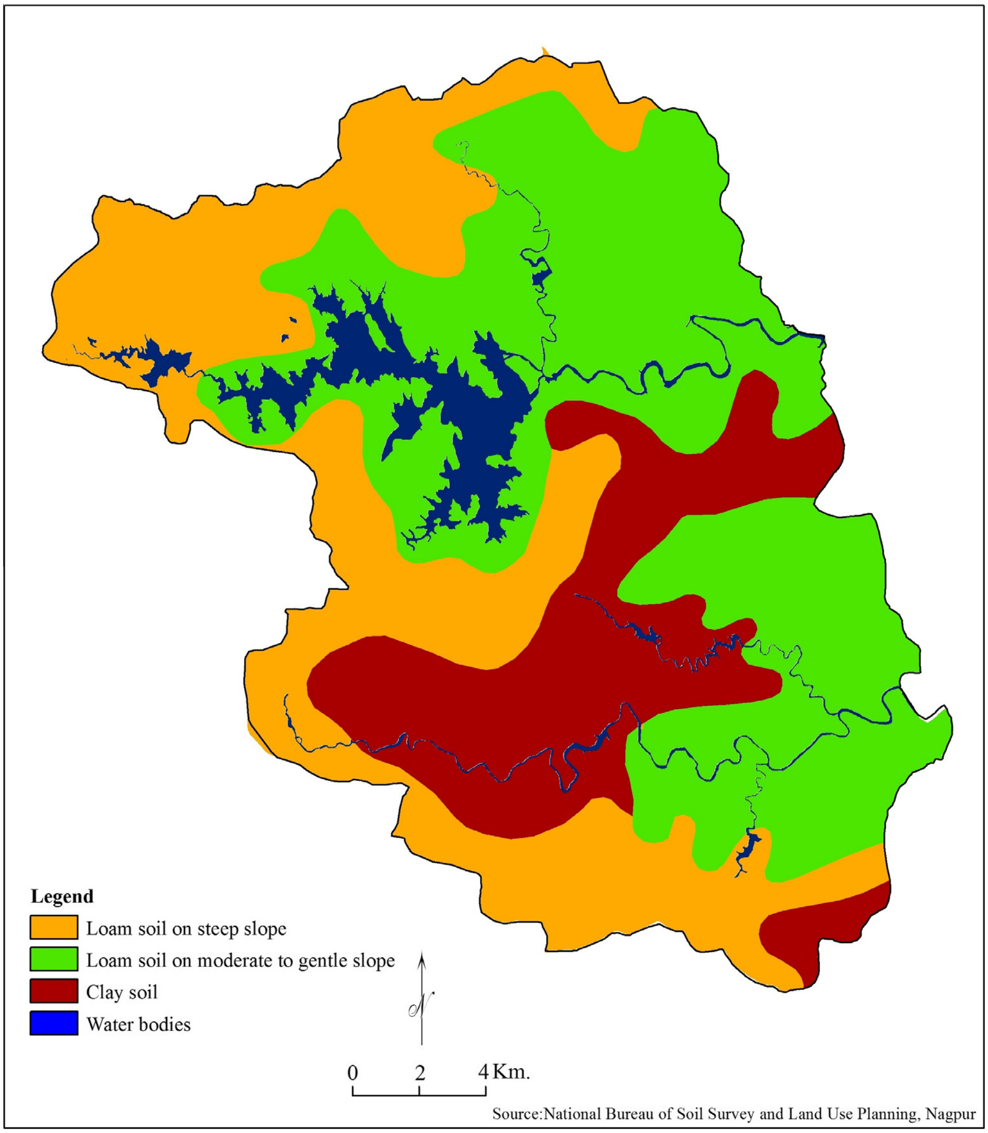

Fig. 5. Distribution of soil texture.

Table 3
Broad classification of soil moisture based on NDWI.

Index values	Soil moisture level	Validity by field check
>0.39	Good soil moisture	Dry
0.28–0.39	Medium soil moisture	Low
0.18–0.28	Less soil moisture	Medium
<0.18	Very less and dry soil	High

information for this study. This information was loaded and analyzed in database software i.e. Comparison for Super Decision Software (CSDS).

3.2. Software and mapping

Remotely sensed data, topographic maps and field data was loaded and processed in GIS software i.e. Arc10 and ERDAS 9.2 [Earth Resource Development Application System]. IRS P6 LISS-IV satellite data was classified using supervised classification technique and field work information collected from selected sample sites for LULC mapping. Normalized Difference Water Index (NDWI) was used for soil moisture map. Thematic maps i.e. pH, EC, OC, N, P and K were prepared using Inverse Distance Weighting (IDW) interpolation technique in GIS. CSDS was used for calculation of weights for selected criterion.

3.3. Criterion

Physical elements have close association with land productivity and agriculture activities (Datye and Gupte, 1984). The criterion like slope, LULC, soil depth, soil texture, soil moisture, soil nutrients, and soil erosion are frequently used for assessment of land qualities and suitabilities for agriculture (Table 1). The influence and affluence of these parameters are varied according to the land characteristics. The correlation technique has been used to understand the association between different variables in the selection process of criterion. Slopes and soil qualities show significant relationship with productivity of major crops like Rice, *Varai, Nagali and Khurasani* (Table 2). Therefore, the criterion i.e. slope, LULC and soil qualities (depth, MWHC, SOC, pH and nutrients) were selected for LSA using weighted overlay analysis (WOA).

Several studies have used GIS layer of soil EC in LSA. However, estimated soil EC in the region is less than one with uniforms distribution and higher suitability for agriculture. Therefore, it is omitted in present LSA.

3.3.1. Slope

The slope analysis is useful to detect the potential sites for agriculture (Bandyopadhyay et al., 2009; Rabia et al., 2013), watershed management (Steiner et al., 2000), afforestation (Bhagat, 2009), etc. The distribution of soil qualities i.e. soil depth, soil moisture, soil texture and availability of nutrients are varied with slopes (Datye and Gupte, 1984). Thin soils are distributed on steep slopes with higher level of erosion whereas deep soils are at gentle sloping ground at the bottom of valleys and foot hill zones. The amount of soil nutrients and minerals not only varied according to environment variables but also amount of soils. Therefore, local variations in soil nutrients, minerals and agriculture productivity vary with soil depth and slope. Crops like *Khurasani, Varai*, *Nagali*, etc. are observed on the moderate slope but rice is cultivated on gentle sloping ground with deep soil. Therefore, variations in slope are positively associated with productivity of *Khurasani* (0.51), *Varai* (0.58), *Nagali* (0.60) and negatively with rice (−0.73) at 0.01 significance level (Table 2). The methods and techniques of cultivation are also change with slope of the land (Akinci et al., 2013).

Land with gentle slopes (16%) is suitable for cultivation management (FAO, 1976) in the study area. About 14% land has moderate slope shows moderate suitability whereas, stiff slopes (40%) marginally suitable for agriculture (Bandyopadhyay et al., 2009; Mustafa et al., 2011). Steep to precipitous slopes (30%) are deeply eroded and have thin soil cover or open rocks and not suitable for agricultural activities. However, some of the areas of gentle, marginally and moderately slopes distributed in forested areas are also not consider for agriculture purposes (Fig. 2).

3.3.2. Land use/land cover (LULC)

LULC classification of the region gives idea about the present status of the land. Several studies like Shalaby et al. (2006), Bandyopadhyay et al. (2009), Chandio and Matori (2011) and Rabia et al. (2013) have used LULC classification for LSA, land evaluation and land use planning. LULC analysis indicates the spatial distribution and characteristics of land like agricultural land, plantation, settlement, fallow land, barren land, mixed trees, built-up land, forest, wastelands, water bodies, etc.

Supervised classification technique i.e. Bayesian Maximum likelihood is used for LULC mapping with nine dominant classes i.e. water body (5.16%), agriculture (9.10%), settlement (0.77%), scrub

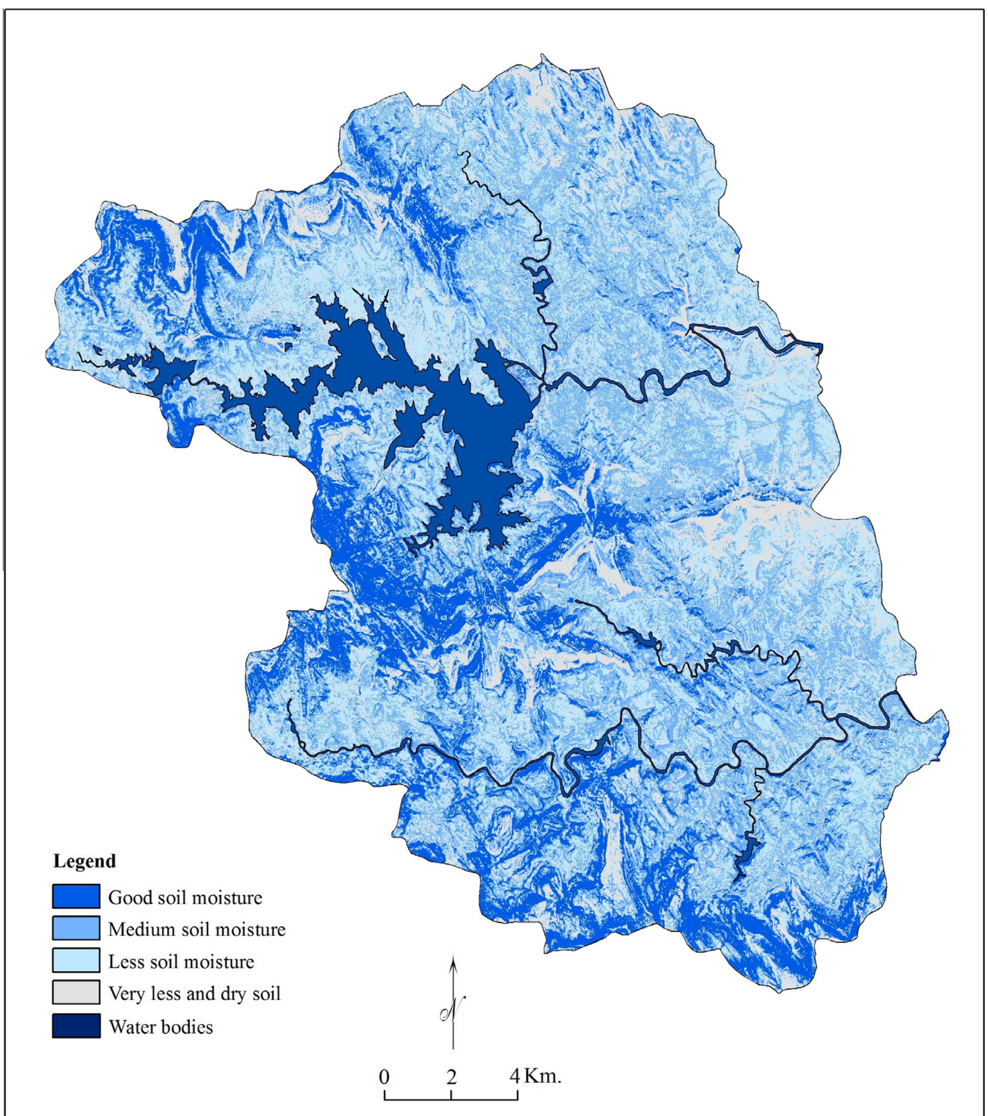

Fig. 6. Distribution of soil moisture.

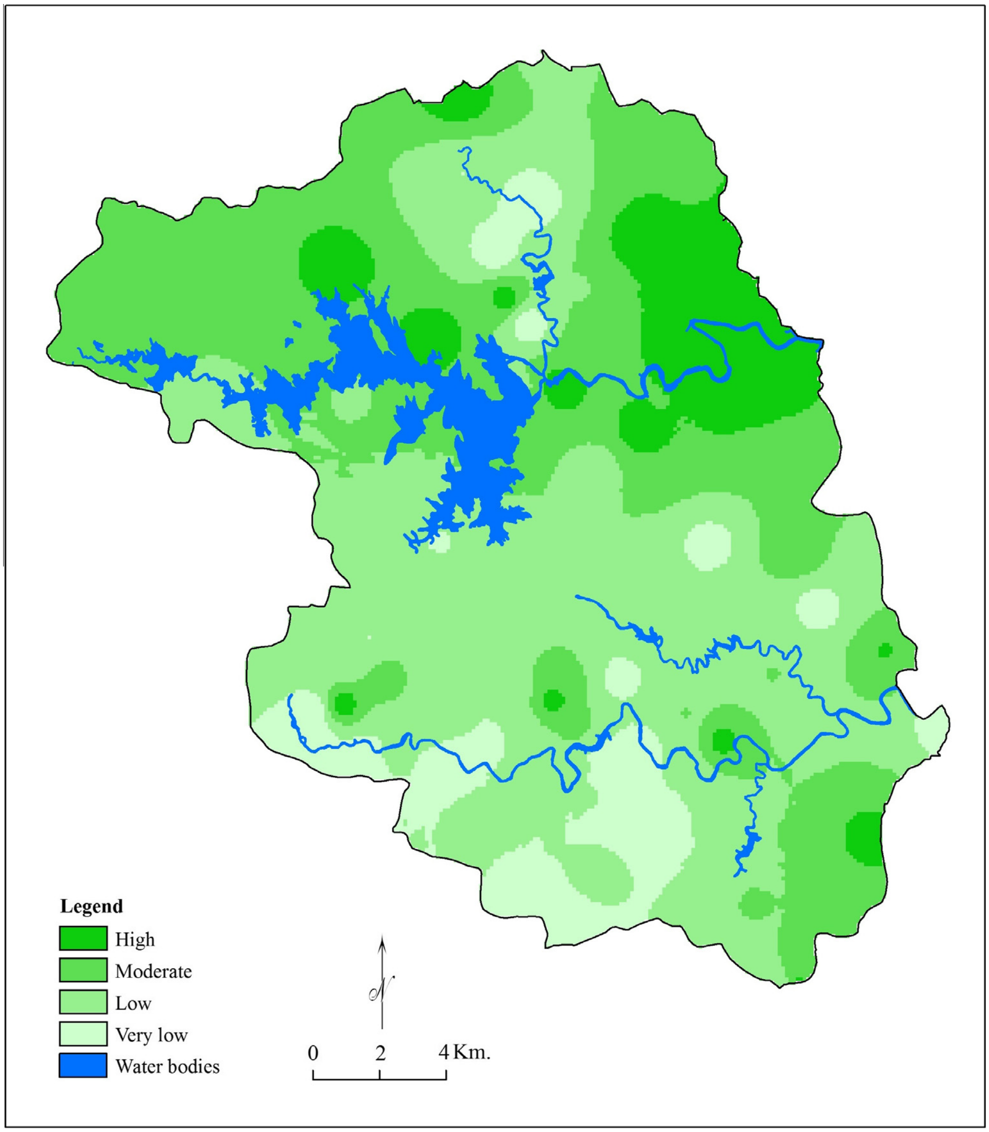

Fig. 7. Maximum water holding capacity.

lands (16.41%), barren land (11.93%), fallow land (10.37%), forest (16.72%), sparse forest (26.14%) and rocky land (3.37%) (Fig. 3). Rocky land, barren land, dense forest, settlement and water bodies are permanently not suitable for agricultural purposes (Bandyopadhyay et al., 2009). Therefore, these classes were merged into the class 'not suitable' using higher weights and lower score in WOA to criterion and sub-criterion, respectively. About 62.04% (27481.07 ha) land is considered for agriculture.

Some of the patches located in reserved forest are also suitable for agriculture. However, these forests cannot be cut for purposes like agriculture. These patches were delineated and omitted using LULC map.

3.3.3. Soil depth

Soil layer is root zone and source of water and nutrients to plants (Akinci et al., 2013). Soil qualities i.e. MWHC (Bhagat, 2014), level of moisture (Zolekar and Bhagat, 2014), amount of soil nutrients (Jobbágy and Jackson, 2001; Dar et al., 2012), rate of infiltration (Rabia, 2012) and growth of plants as well as agricultural productivity (Yu et al., 2011) varies according to the soil depth. Availability of nutrients i.e. N (0.82), P (0.61) and MWHC (0.95) has significant positive relationship with soil depth at the 0.01 level. Soil depth is negatively associated with productivity of *Khurasani* (−0.38), *Varai* (−0.16), *Nagali* (−0.14) and positively with Rice (Table 2). Farmers in the region are selecting their cropping pattern according to the soil depth and slope. Crops like *Khurasani*, *Varai*, *Nagali*, etc. are observed on shallow soils with low MWHC whereas rice on deep soils at bottom of the valleys.

Slope map, LULC map and field data were used to prepare the map of soil depth. Rocky, barren and scrub land are included into the soil class, 'thin and shallow'. Agriculture lands, fallow lands and dense forest are classified into the soil classes viz. deep, moderate and marginal depth, respectively. About 23.67% of TGA (9941.77 ha) have deep soils and distributed in narrow tracks near to the river Mula and Pravara. These soils are more suitable for agricultural activities. Moderate (42.08%) and marginally deep soils (17.31%) are distributed on moderate to stiff slopes. Shallow soils observed in 12.58% of reviewed lands and thin soils in 4.37% (Fig. 4).

3.3.4. Soil texture

Soil properties i.e. MWHC, EC, pH, buffering capacity, salinity, soil structure, nutrients i.e. SOC, N, P, K and biological elements i.e. microbial biomass are varies with soil texture (Girvan et al.,

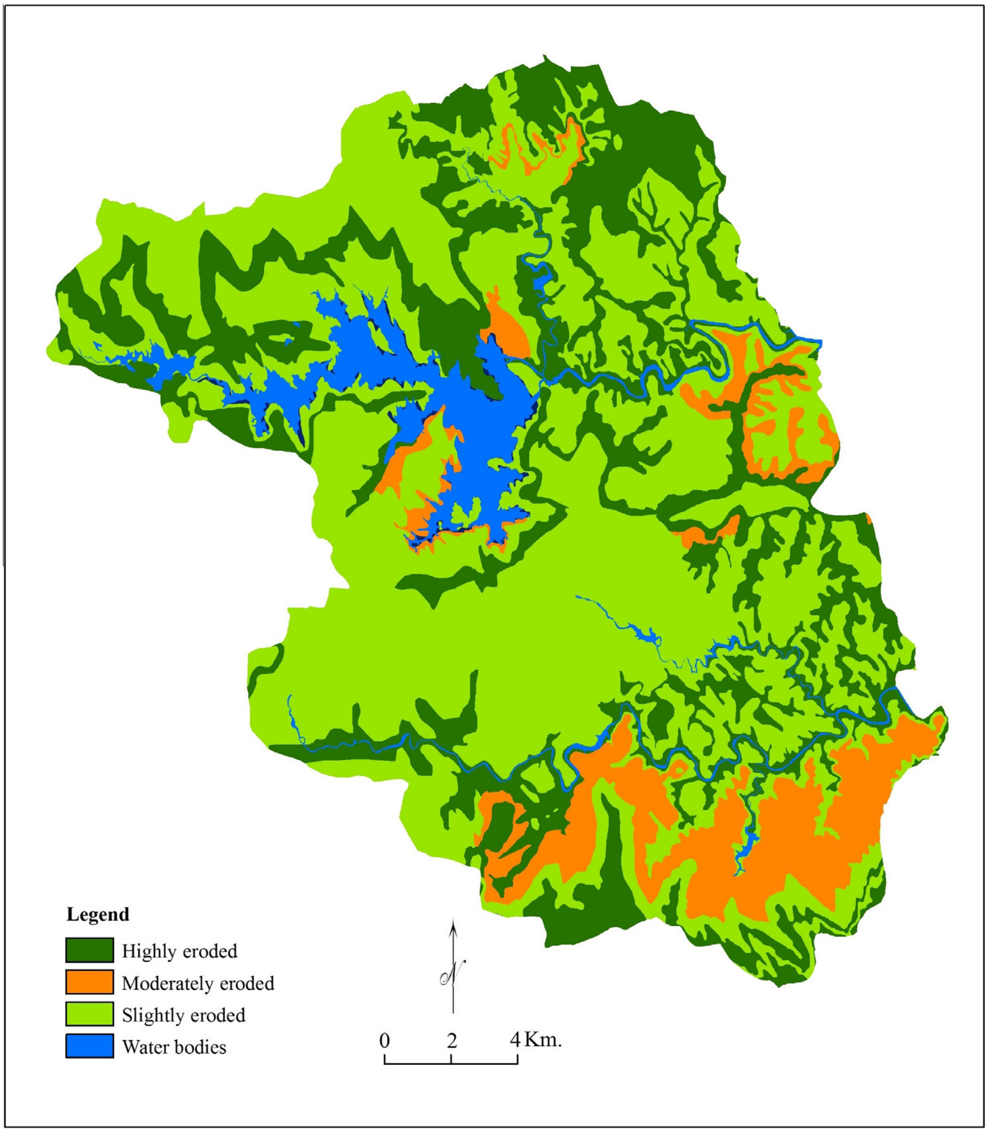

Fig. 8. Intensities of soil erosion.

2003; Mojid et al., 2009; Mustafa et al., 2011; Bhagat, 2014). Therefore, the scholars like Olaleye et al. (2008), Jafari and Zaredar (2010), Mustafa et al. (2011), etc. have used textural classification for LSA for agriculture.

The soil texture map is procured from National Bureau of Soil Survey and Land Use Planning, Nagpur (Fig. 5) and used for LSA in the present study. Loam soils and clay loam are major soil types in the region. Loam soils are red[2] to reddish brown in color covered 72.49% (31,820 ha) of lands on gentle to steep slopes. Clay loam soil is mixture of sand, silt and clay with ratio of 3:3:4, respectively (FAO, 1976). Clay soils are distributed (9356 ha) on slightly dissected foot hill zones with moderate to gentle slopes. The area of clay soils is more in the Mula basin than the Pravara basin. Most of the red soils are formed in condition of high temperature, heavy rainfall, high weathering of igneous rocks (Dar et al., 2012). The red color of soils in the study area indicates higher proportion of iron. These soils are rich in potash but phosphate, manganese and zink are at marginal level.

[2] For interpretation of color in Figs. 5 and 15, the reader is referred to the web version of this article.

3.3.5. Soil moisture

The spectral reflectance is varied according to land characteristics including soils, rocks, water bodies, vegetation cover, built-up area, etc. Water has low spectral reflectance than the other surface due to strong absorption (Hui et al., 2008). Therefore, wet soils are appeared darker than dry surface in RS images (Zhang and Voss, 2006). Some of the studies like Gao (1996), Jain et al. (2005), Xu (2006), Bhagat (2009), Bhagat and Sonawane (2011), Zolekar and Bhagat (2014), etc. have detected water bodies and soil moisture, successfully using calculated Soil Wetness Index (SWI) and Normalized Difference Water Index (NDWI).

Soil moisture is good indicator of soil qualities and has positive relationship with crop yield (Bhagat, 2009; Wang et al., 2012). The amount of the soil moisture varies with soil depth and texture (Zolekar and Bhagat, 2014). NDWI is good indicator of soil moisture and sensitive to water content in vegetation (Fensholt and Sandholt, 2003). Therefore, NDWI was calculated (Eq. (1)) using Infra Red (IR) and Green (G) bands of IRS P6 LISS-IV satellite for soil moisture mapping.

$$NDWI = \frac{IR - G}{IR + G} \tag{1}$$

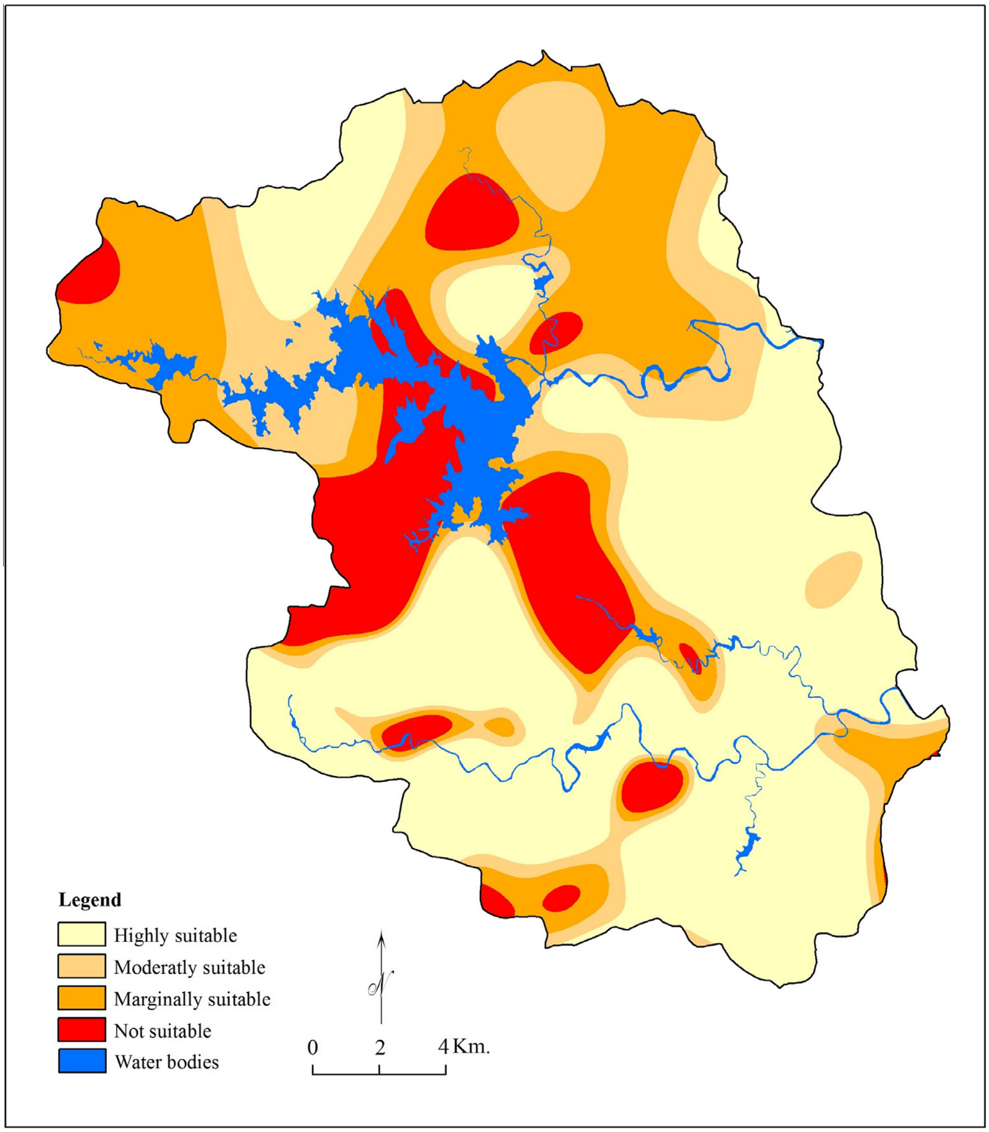

Fig. 9. Distribution of soil organic carbon.

The calculated values were broadly grouped into four soil moisture classes (Table 3) for detection of LS. Dense forest with deep soils was classified into the class 'high soil moisture' and the 'medium soil moisture' for agriculture, fallow and sparse forests (Fig. 6). However, NDWI values less than 0.01 were calculated for pixels of water bodies and shadows on steep slopes and classified in the class 'Very less and dry soil'. Therefore, the major water bodies in the study area were masked to delineate and separate from other classes.

3.3.6. Maximum water holding capacity (MWHC)

The field capacity of soil is defined as the amount of water that can be hold in the capillaries of soil agents and the pull of gravity (Burke, 2009). MWHC of soils are varies by soil depth, soil texture, inorganic and organic contents in the soil. The leaching process of nutrients and minerals are depending on soil texture and available soil water. Soil water holding capacity determines availability of water, cropping pattern, need of irrigations (Bhagat, 2014). Therefore, GIS layer of MWHC of soil is useful in LSA for agriculture.

Selected soil samples have analyzed in laboratory to estimated MWHC. These estimated values were used for mapping using IDW interpolation technique to estimate the spatial distribution (Fig. 7). MWHC depicts significant positive relationship with soil depth (0.95) and rice productivity (0.79) and negative with slope (−0.64) and productivity of *Khurasani* (−0.40) at 0.01 level and *Varai* (−0.23) at 0.05 significance level (Table 2). Deep and clay soils are distributed in gentle sloping ground with higher MWHC.

3.3.7. Soil erosion

Soil erosion removes fertile top soil with physical, chemical and biological properties in hilly zones with higher rainfall like study area (Akinci et al., 2013). Higher elevation shows higher erosion due to steep slopes and higher rainfall. About 16.51% reviewed lands are highly eroded. However, soils are carried out from steep slopes and deposited on gentle sloping ground at foot hill zones and bottom of the valley. About 14.25% of lands in the area are moderately eroded and 64.06% is slightly (Fig. 8).

3.3.8. Soil organic carbon (SOC)

SOC is ideal source of nutrients (Bandyopadhyay et al., 2009) and plays important role in soil fertility, complex water and nutrient exchange processes in plant root zone and land degradation (Bhagat, 2013). SOC indicates organic matter content in soil which often creates the basis for successful use of mineral fertilizers.

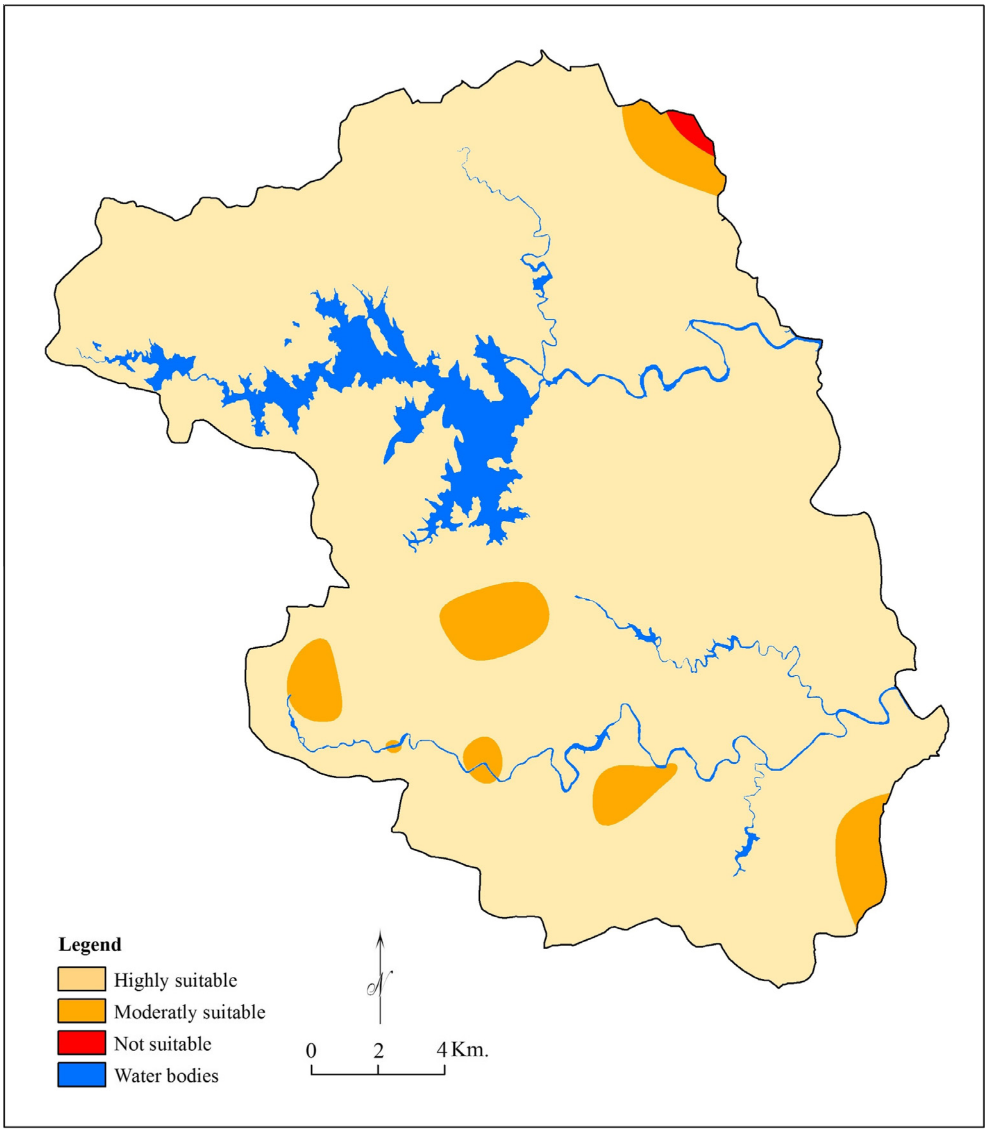

Fig. 10. Distribution of pH.

Losses of SOC are negatively affect the agriculture and plant life mainly in downstream zones (Bhagat, 2013). SOC prevents plant growth and soil process in different climatic condition and agricultural practices. Soil organic matter varies spatially with natural soil quality and soil management. Therefore, SOC map prepared using laboratory data and IDW interpolation technique (Fig. 9). The average SOC in the study area is 0.8% and classified into the category, 'highly suitable'. SOC is more in Mula basin than the Pravara and classified into the class highly suitable for LS. SOC in Pravara basin is comparatively less and marginally to moderately suitable for agriculture. It is also varies according to elevation, slope and rainfall. Areas of higher elevation, steep slopes and higher rainfall show comparatively lesser amount of SOC.

3.3.9. Potential of hydrogen (pH)

Soil pH is playing the major role in nutrient availability, plant growth and productivity (Thompson and Troeh, 1973). pH provides the information about availability of nutrients and phyto-toxity as well as land suitability for specific crops (Mustafa et al., 2011). pH below 7 is acidic and above 7 is alkaline. However, the optimum pH range for many plants is between 5.5 and 7.0. pH values in the region varies from 5.7 to 7.8. The average value of pH is 6.5 and highly suitable for agriculture and plantation (Fig. 10).

3.3.10. Nitrogen (N)

Nitrogen is essential for plant growth basically leaf and stem development and production (Chapin and Shaver, 1985). SOC is one of the sources of N. Soil samples collected from study area are analyzed in laboratory to estimate amount of N. GIS layer of N was prepared using these values and IDW interpolation technique in GIS. Nitrogen is soluble in water and leached out in high rainfall zone like our study area. Mula basin shows more area with nitrogenous matter than Pravara basin. About 28.18% area is moderately suitable for agriculture. Only 2.83% area shows marginal suitability (Fig. 11).

3.3.11. Phosphorus (P)

Phosphorus is important for root formation and growth, crop maturity, stimulate flowering, seed production, etc. Acidic or alkaline soil required more P supply for healthy plant growth. Therefore, *P* is detected and estimated based on laboratory analysis and used for LSA. A maximum value of *P* is estimated 51.8 kg./ha

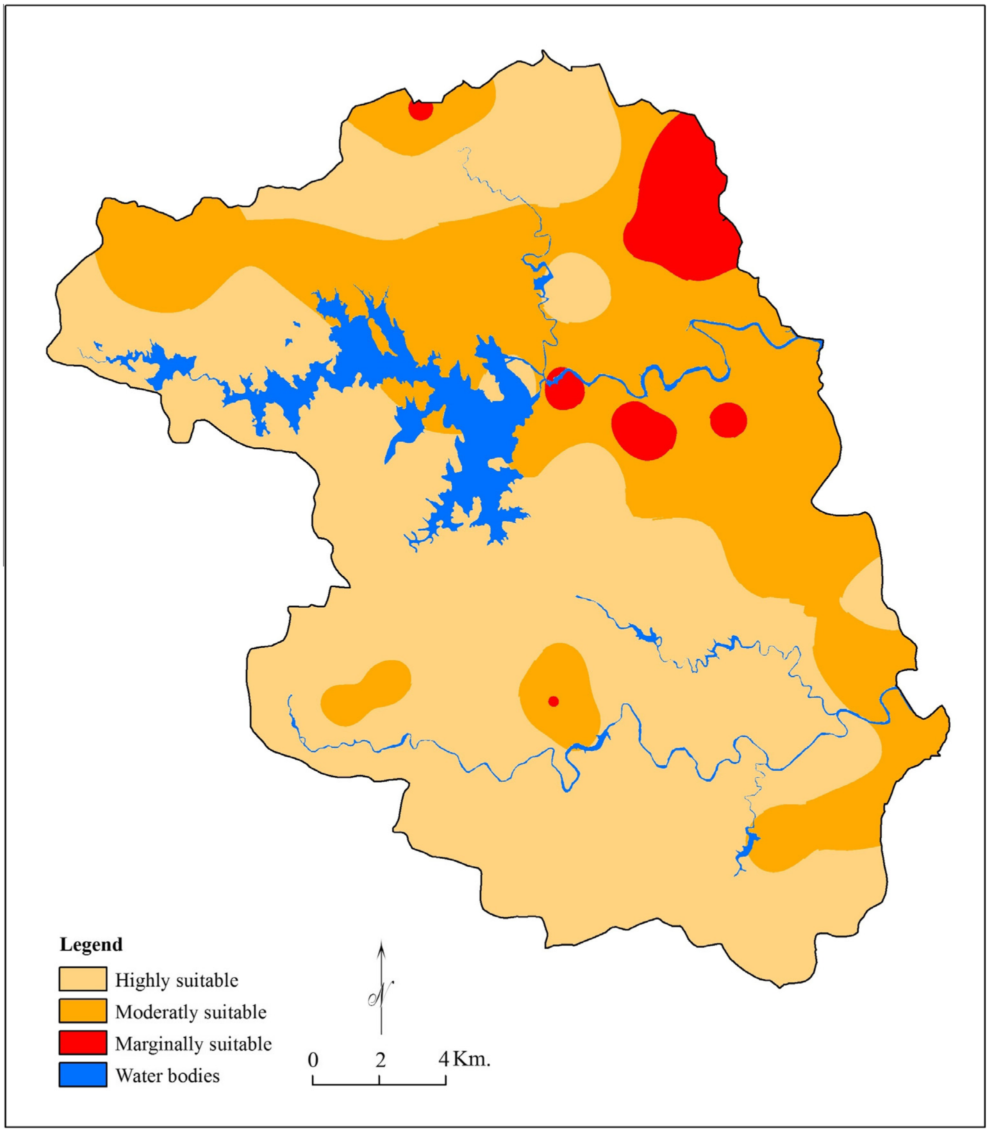

Fig. 11. Distribution of nitrogen.

and minimum 8.9 kg./ha with average value of 17.39 kg/ha P shows marginal suitability for agriculture in this area (Fig. 12).

3.3.12. Potassium (K)

Potassium is important for many functions of plants i.e. (1) photosynthesis activity, (2) adds stalk and stem stiffness, (3) disease resistance, (4) drought tolerance, (5) plumpness to grain and seeds, (6) firmness, texture, size and color of fruits, and (7) oil content in oil seeds. Potash deficiency losses plant's green color, turns yellow, the lower leaves fall off and reduces productivity.

Soil K content in the study area (Fig. 13) is highly suitable (395.6 kg/ha) in the clay soils in upper Mula basin (527.8 kg /ha) whereas Pravara basin (215 kg/ha) shows comparatively less amount of K (28 kg/ha to 784 kg/ha). Wakene (2001) reported that the spatial variation in amount of K depends on the intensity of cultivation, soil management and soil particles size. Pravara basin shows intensive cultivation than the Mula basin.

3.4. Analytic hierarchy process (AHP)

AHP is one of the MCDM methods originally developed by Prof. Thomas L. Saaty in 1960s for solving complex spatial problems (Malczewski, 2006; Attua and Fisher, 2010; Chandio et al., 2011; Samanta et al., 2011; Yu et al., 2011) related to LS (Mustafa et al., 2011; Rabia and Terribile, 2013), land use planning (Nyeko, 2012), public policies and political strategies (Velasquez and Hester, 2013), etc. The hierarchical structure of AHP is useful for complex spatial decision with higher confidence level (Saaty, 1980). Several researchers are attracted to AHP for its effective mathematical properties i.e. weight determination through pairwise comparisons of criterion and score for sub criterions (Trainta-phyllou and Mann, 1995; Cengiz and Akbulak, 2009; Bandyopadhyay et al., 2009; Mustafa et al., 2011; Rabia and Terribile, 2013). This technique can evaluate complexities with their importance (Saaty, 1980). Inconsistency ratio measures the inconsistency of decision makers' judgments (Mustafa et al., 2011) therefore, it minimizes the judging errors within own mechanism (Cengiz and Akbulak, 2009). It is more flexible technique with higher precision in LSA (Malczewski, 2006). Wijnmalen and Wedley (2008) reported that the ranks assigned to the criterion have to be reversed according to additions and delineation of criterion. However, reported opinions about ranks and weights assigned to selected criterion in this study shows bias judgment influenced by the respondent. Therefore, correlation analysis has

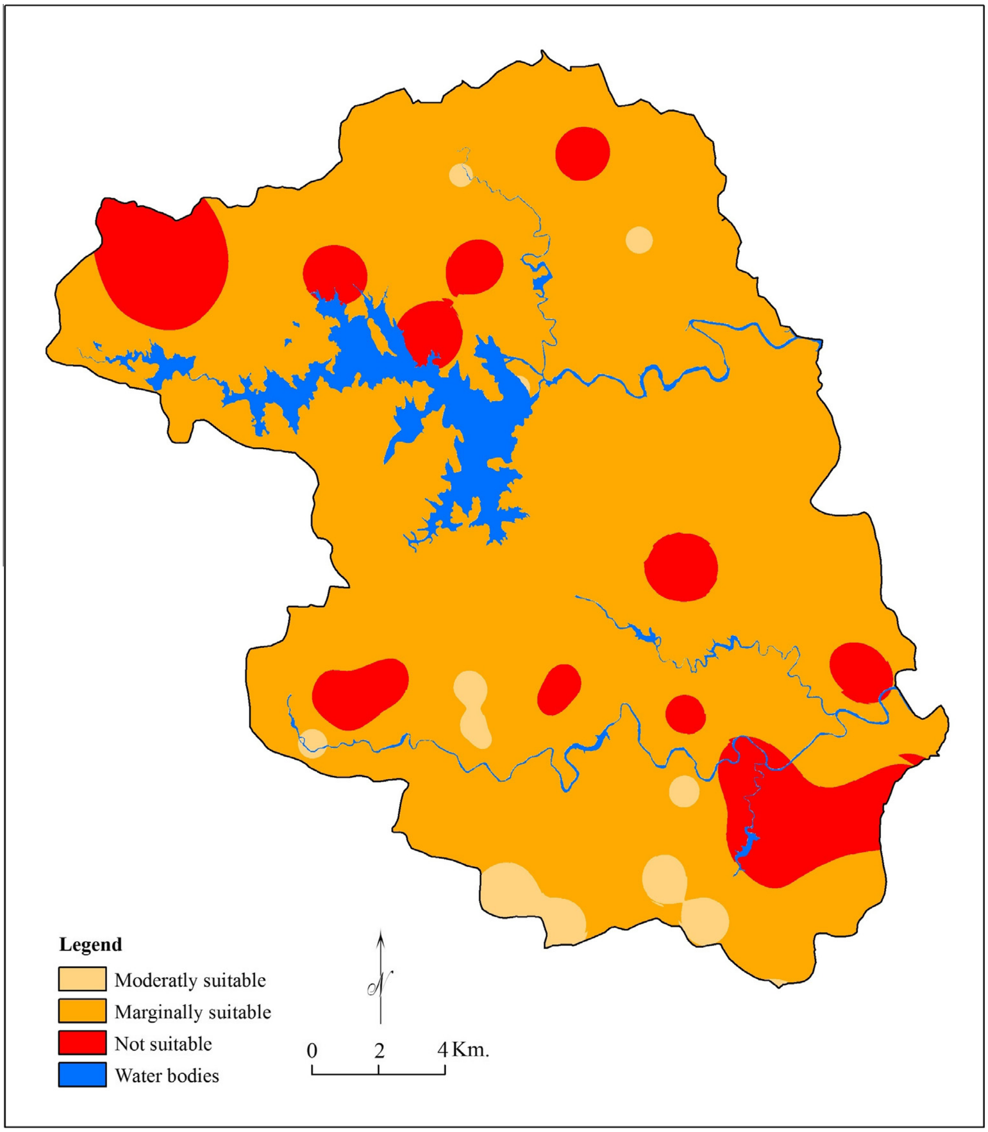

Fig. 12. Distribution of phosphorus.

been adopted for robust judgment of ranking and calculation of weights for criterion and assignment of the score for sub-criterion.

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 (Fig. 14).

3.4.1. Determination of ranks

The experts' opinion and correlation analyses were used for determination of ranks (1–12) of criterion. Rank indicates the importance level of parameters. 21 experts in LSA have responded and assigned the ranks asked criterion.

Slope, LULC, soil depth and soil texture have more influence on agricultural yields in hilly zone and ranked 1–4, respectively. The criterion like soil moisture (rank 5), erosion (rank 6) and MWHC (rank 7) vary according to slopes and soil depth with medium influence on agricultural production. OC, pH, N, P, and K show comparatively less significance with crop yield (Table 2) and ranked least (8–12) (Table 4).

3.4.2. Pairwise comparison matrix (PCM)

The experts' opinions were used to decide the ranks of influencing criteria and PCM in CSDS used to determine the weights. The PCM required for AHP procedure based on forming judgments between two criteria and attempting to prioritize entire list of parameters (Saaty, 1997). The pairwise comparison analysis helps for decision makers to assign different levels of importance of factors involved in LS (Elaalem, 2012). LSA studies have assigned weights according to their relative importance and land characteristics (Mokarram et al., 2007; Bandyopadhyay et al., 2009; Mustafa et al., 2011; Elaalem, 2012; Rabia and Terribile, 2013). The advantage of this method is that all alternatives are contributed in LSA (Rabia and Terribile, 2013). Therefore, PCM was prepared to determine the weights of parameters according to the AHP. Ranks indicate strength and dominance of criterion. Assigned ranks (1–12) were used to judge the importance of criterion in PCM (Table 5).

3.4.3. Calculation of weights

The weights of criterion were calculated in four steps in PCM of CSDS i.e. (1) formation of judgements, (2) calculation of assigned ranks, (3) preparation of Normalised Pairwise Comparison Matrix (NPCM) and finally, (4) calculation of weights. Judgements of ranks were formed based on expert opinion (Table 5) and compared in PCM. The cell values of PCM were divided by sum of the column to obtain the cell values in NPCM and averaged in row to calculate the weights of criterion (Table 6) (Akinci et al., 2013). These,

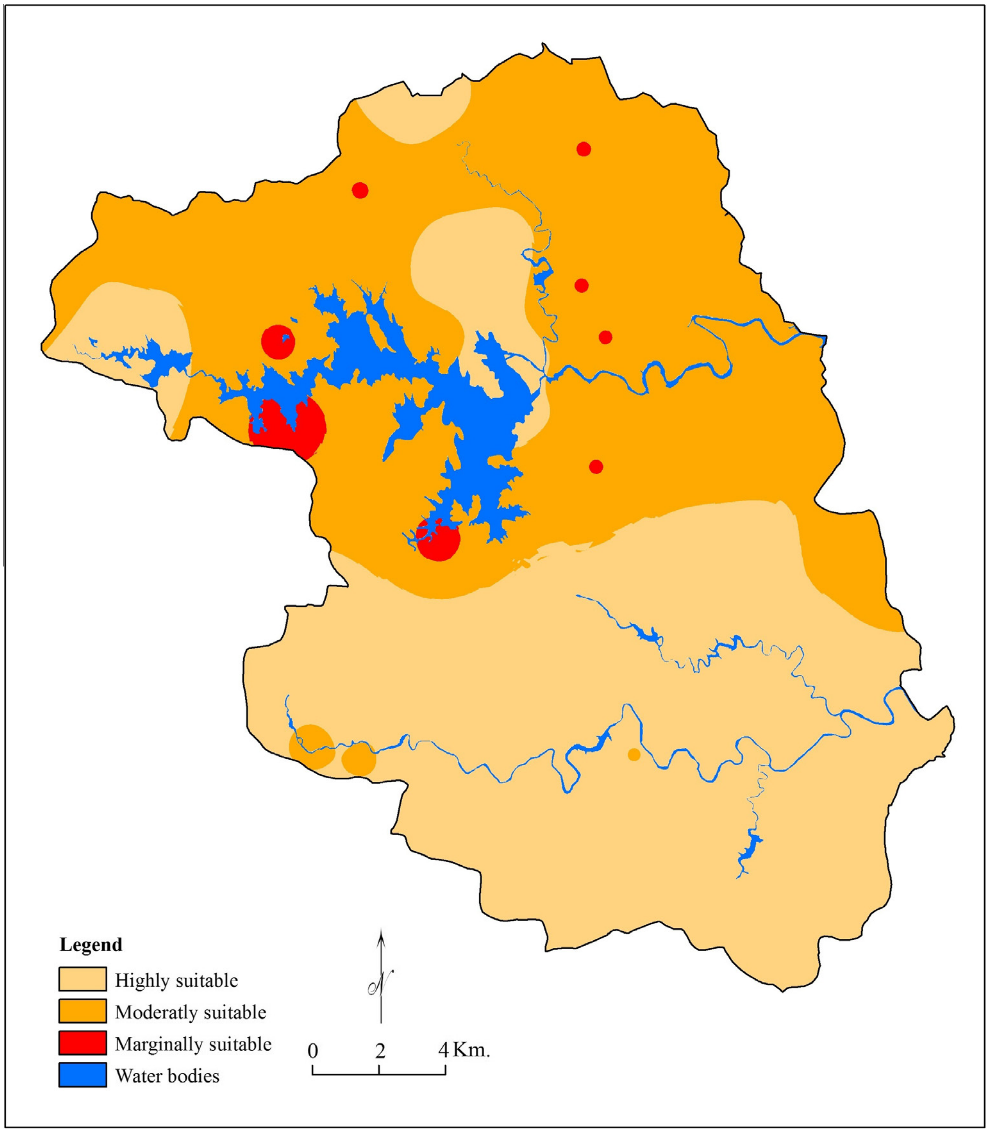

Fig. 13. Distribution of potassium.

calculated weights were scaled from 0 to 1 in ascending order to maintain hierarchy according to their importance in LSA.

The accuracy of the calculated weights PCM depends on the consistency of judgments of ranking the criterion. Consistency Ratio (CR) measures logical inconsistency of the judgments and facilitate identification of possible errors (Cengiz and Akbulak, 2009). Saaty (1997) suggests acceptable CR values up to 0.1. Therefore, it is suggested that PCM should be revised according to improved judgement, if the CR excides the upper limit (0.1) (Akinci et al., 2013). In the present analysis, calculated CR is zero and estimated weights of selected criterion are acceptable for LSA. Further, the estimated values of weights are converted into percentage for weighted overlay analysis in GIS (Table 7).

3.4.4. Determination of score

FAO (1976) have used land qualities and requirement of land use for LS classification. Researchers like Bandyopadhyay et al. (2009) and Akinci et al. (2013) have assigned the score for sub-criterion i.e. distribution classes from 1 to 10 based on favorable conditions and limitations for agricultural practices. The higher score indicates maximum influence of sub-criterion whereas lesser score shows least suitability for agriculture (Table 7). Scores for selected criterion i.e. slope, LULC, soil depth, soil texture, soil erosion, SOC and primary soil nutrients were assigned, accordingly.

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 eight 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 (6–12°) with moderate deep soil and slightly undulating topography (Akinci et al., 2013). Some patches of very steep to extra steep sloping lands (12–30°) show potentials of terracing but there are limitations like not easy accessible, thin soils, less soil moisture, highly dissected and maximum percolation (Zolekar and Bhagat, 2014). These classes were classified in the class, 'marginal suitable' with score four (Table 7).

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. Many of fallow lands are distributed in foot hill zones with moderate deep soils. Therefore, score eight assigned to this fallow land which shows potentials for agricultural extensions. Score six for moderate suitability, is assigned to the land suitable for agriculture and distributed in sparse forest with

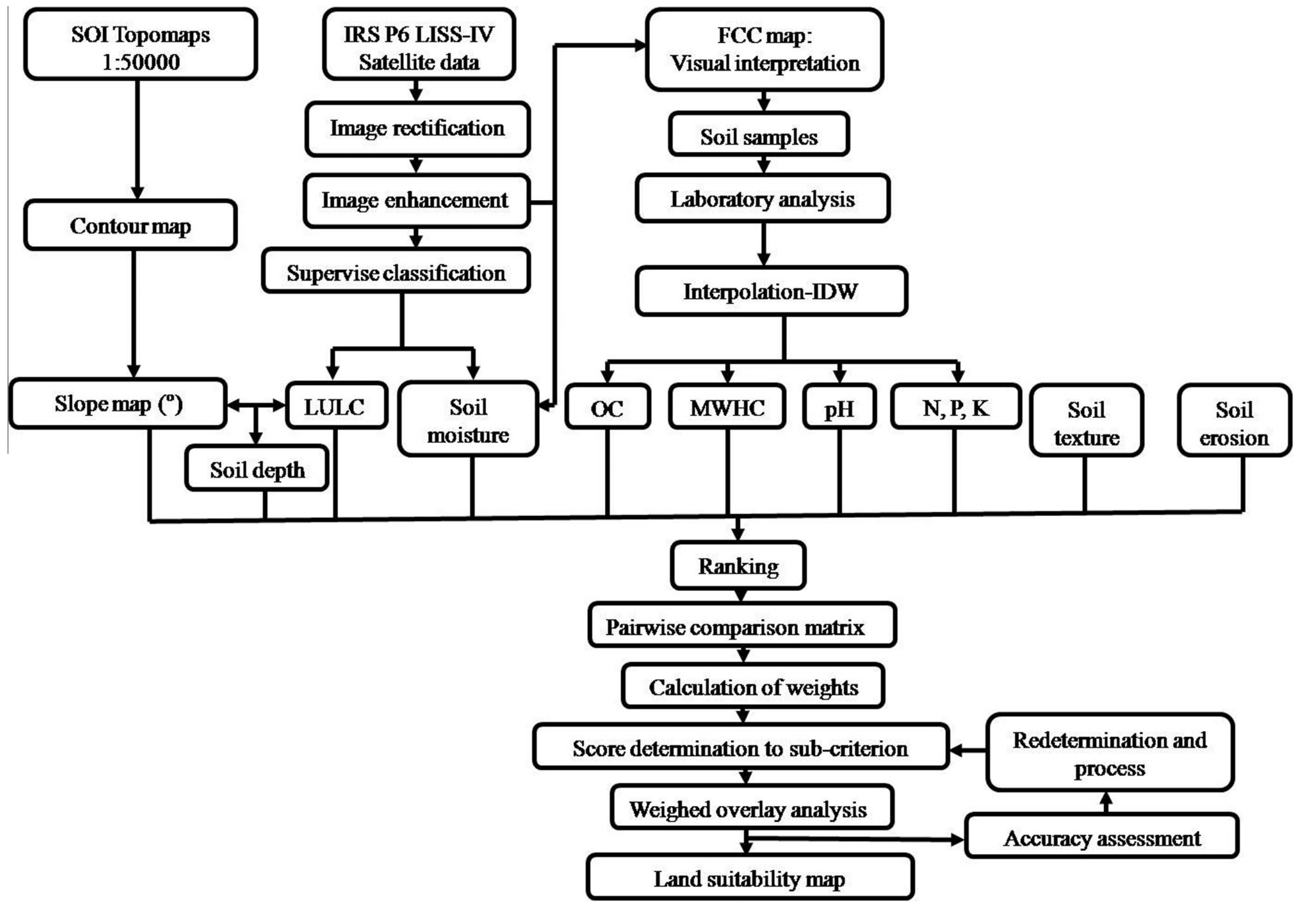

Fig. 14. Schematic preparation of image processing and land suitability analysis.

Table 4
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 5
Pairwise comparison matrix.

Criteria	Slope	LULC	Depth	Texture	Soil moisture	Erosion	MWHC	SOC	pH	N	P	K
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
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
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
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
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
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
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
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
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
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
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
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

moderate slopes and shallow soils. Scrub lands with steep slopes with shallow soils are marginally suitable for agriculture whereas barren and rocky lands are not suitable for agriculture. The study area is part of the Western Ghats in Maharashtra (India) which is considered as environmentally protected zone (Zolekar and Bhagat, 2014). Therefore, the dense forested areas were classified into the class 'not suitable' with rank one. Score one is assigned to water bodies for all layers (Table 7).

Deep soils are favorable for growth and development of plant roots with higher supply of nutrients and minerals. Bandyopadhyay et al. (2009) and Akinci et al. (2013) were assigned maximum score (10) to deep soils and lesser (1) to thin soils with

Table 6
Normalized pairwise comparison matrix.

Criteria	Slope	LULC	Depth	Texture	Soil moisture	Erosion	MWHC	SOC	pH	N	P	K	Weight
Slope	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.0	9.0	10.0	11.00	12.0	0.32
LULC	0.50	1.00	1.50	2.00	2.50	3.00	3.5	4.00	4.50	5.00	5.50	6.00	0.16
Depth	0.33	0.67	1.00	1.33	1.66	2.00	2.33	2.66	3.00	3.33	3.66	4.00	0.11
Texture	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	0.08
Soil moisture	0.20	0.40	0.60	0.80	1.00	1.20	1.40	1.60	1.80	2.00	2.20	2.40	0.06
Erosion	0.16	0.33	0.50	0.67	0.83	1.00	1.16	1.33	1.50	1.66	1.83	2.00	0.05
WHC	0.14	0.29	0.43	0.57	0.71	0.86	1.00	1.14	1.28	1.43	1.57	1.71	0.05
SOC	0.12	0.25	0.38	0.50	0.63	0.75	0.88	1.00	1.12	1.25	1.37	1.50	0.04
pH	0.11	0.22	0.33	0.44	0.56	0.67	0.78	0.89	1.00	1.11	1.22	1.33	0.04
N	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	0.03
P	0.09	0.18	0.27	0.36	0.45	0.55	0.64	0.73	0.82	0.91	1.00	1.09	0.03
K	0.08	0.17	0.25	0.33	0.42	0.50	0.58	0.67	0.75	0.83	0.92	1.00	0.03

Table 7
Weights and scores.

Criteria	Weight	Influence (%)	Sub-criterion (with ranges)	Area (ha)	Score
Slope (°)	0.32	32	Gentle (0–1)	1946	10
			Moderate (1–3)	4679	10
			Stiff (3–6)	5776	8
			Steep (6–12)	8523	6
			Very steep (12–20)	8520	4
			Extra steep (20–30)	7314	4
			Precipitous (30–90)	5252	1
LULC	0.16	16	Agriculture	4033	10
			Fallow land	4594	8
			Sparse forest	11,582	6
			Scrub land	7271	4
			Barren land	5285	1
			Dense forest	7409	1
			Settlement	340	1
			Rocky land	1494	1
			Water body	2287	Restricted
Depth (cm)	0.11	11	Deep soil	9942	10
			Moderate depth	17,677	7
			Marginal depth	7271	6
			Shallow soil	5285	4
			Thin soil	1835	1
Texture	0.08	8	Loam soils with moderate to gentle slope	18,890	10
			Clay loam	14,685	7
			Loam soils on steep slope	8434	4
Soil moisture	0.06	6	Good soil moisture	7551	10
			Medium soil moisture	15,616	7
			Less soil moisture	11,865	4
			Very less and dry soil	6977	1
Soil erosion	0.05	5	Slightly eroded	28,380	10
			Moderately eroded	6315	7
			Highly eroded	7314	1
Soil OC (%)	0.05	5	Highly suitable (0.61–1.00)	19,625	10
			Moderately suitable (0.40–0.60)	7639	7
			Marginally suitable (0.20–0.40)	9485	5
			Not suitable (<0.20)	5260	1
MWHC	0.04	4	High (>400)	7583	10
			Moderate (200–400)	13,328	7
			Low (200–100)	14,518	4
			Very low (<100)	6580	1
pH	0.04	4	Highly suitable (5.00–7.3)	39,699	10
			Moderately suitable (7.3–8.0)	2227	7
			Not suitable (>8)	83	1
N (kg/ha)	0.03	3	Highly suitable (>225)	29,819	10
			Moderately suitable (181–225)	11,001	7
			Marginally suitable (95–180)	1190	4
P (kg/ha)	0.03	3	Moderately suitable (31–65)	913	7
			Marginally suitable (16–30)	39,781	4
			Not suitable (<15)	1315	1
K (kg/ha)	0.03	3	Highly suitable (>360)	15,475	10
			Moderately suitable (181–360)	22,548	7
			Marginally suitable (121–180)	3987	4

Table 8
Error matrix: accuracy assessment.

	Reference class					
	Highly suitable	Moderately suitable	Marginally suitable	Not suitable	Total sample	User's accuracy (%)
Classified classes						
Highly suitable	37	03	01	00	41	90.24
Moderately suitable	01	26	02	00	29	89.65
Marginally suitable	00	05	36	01	42	85.71
Not suitable	00	00	02	42	44	95.45
Total sample	38	31	44	43	156	
Producer's accuracy (%)	97.36	83.87	88.63	97.67		90.38

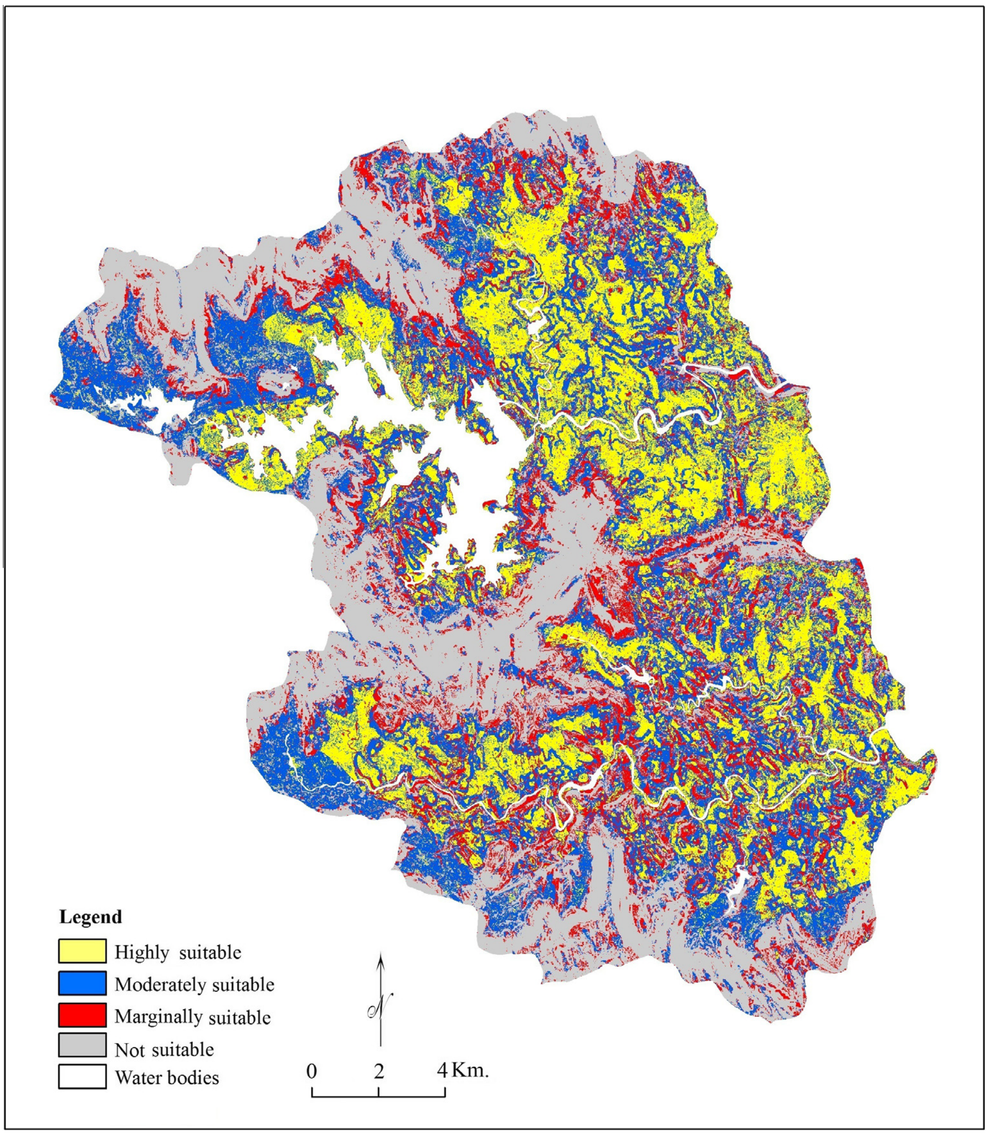

Fig. 15. Land suitability for agriculture.

rocky patches. Seven score assigned to moderate deep soils (50–90 cm) with stiff slopes at foot hill zone. Marginally deep soils are distributed on micro terraces assigned the score, six. Shallow soils with low WHC show crops like *Nagali, Varai, Khurasani,* etc. assigned score, four. Soil MWHC shows positive association with soil depth (0.95) (Table 1). Therefore, similar scores were assigned to the classes of soil MWHC i.e. high (10), moderate (7), low (4) and very low (1) (Table 7).

Normally, lands with good soil moisture are suitable for agriculture however, these soils in the study area are covered by dense forest and not available for agricultural purposes therefore, score one is assigned to the class good soil moisture in the classified NDWI image. The classes medium soil moisture, less soil moisture, very less soil moisture are moderately suitable (7), marginally suitable (4) and not suitable (1) for agricultural activities, respectively (Zolekar and Bhagat, 2014).

Sub-criterion of primary nutrients, SOC and pH were classified into suitability levels viz. highly suitable (10), moderately suitable (7), marginally suitable (4) and not suitable (1) for agriculture (FAO, 1976) (Table 7).

FAO (2006) and Isitekhale et al. (2013) have reported that loam soils are highly suitable and clay loam soils are moderately suitable for agriculture. Therefore, maximum score (10) was assigned to loam soils with gentle to moderate slope and seven for clay loams. Score, four was assigned to shallow and thin loam soils (Table 7).

Erosion is a major limiting factor of the LS for agriculture. Slightly eroded, moderately eroded and highly eroded lands are assigned score, ten, seven and one respectively (Akinci et al., 2013) (Table 7).

3.4.5. Weighted overlay analysis

The weighted overlay analysis is useful to solve complex spatial problems in site selection and suitability (Girvan et al., 2003) based on common measurement of diverse and dissimilar inputs (Kuria et al., 2011). AHP is used to discover the influential factors in hierarchy of given inputs to WOA (Parimala and Lopez, 2012). Therefore, all thematic layers were integrated with each other in GIS using the weighted overlay technique. LS for agriculture have been extracted using WOA techniques based on MCDM and AHP. Selected raster maps were overlaid by converting their cell values to common scale, assigning a weight to each criterion and adding the weighted cell values together (Mojid et al., 2009). The cell values of each input raster layer are multiplied by their weight (Cengiz and Akbulak, 2009).

$$S = \sum_{i=1}^{n} wi\ xi \text{ (after Cengiz and Akbulak, 2009)} \qquad (2)$$

where S = total LS score, wi = weight of LS criteria, xi = sub-criteria score of i LS criteria, n = total number of LS criteria.

Then output raster map was calculated (Eq. (2)) and allotted scores were averagely converted into four classes i.e. 9, 7, 4 and 1. Finally, these classes were reclassified into the four suitability levels i.e. highly suitable, moderately suitable, marginally suitable, and not suitable according to the classification of Food and Agriculture Organization (FAO, 1976) classifications.

3.4.6. Accuracy assessment

Accuracy assessment is the comparison between classified data (output) and reference data (Comber et al., 2012; Bhagat and More, 2013). The resulting cross tabulation of classified data against reference data is commonly known as error matrix (Comber et al., 2012). The accuracy was estimated at the users, producers and overall accuracy using error matrix (Congalton, 1991). The accuracy assessment method was not only used for knowing accuracy

Table 9
Land suitability classes.

Suitability levels	Area		Land characteristics/qualities	Remarks
	ha	%		
Highly suitable	7326	17	Gentle to stiff slopes (0–6°) with gullies Soil depth more than 90 cm, Loam texture Good WHC High soil moisture pH high to moderate (6–7.5) Slightly erosion Paddy with fallow land	Highly suitable land for agriculture. Intensive agriculture is possible if irrigation facilities are available
Moderately suitable	12,372	29	Stiff slopes (6–12°) with micro terracing Deep soils at foot hill zone (50–90 cm) Loam texture Moderate WHC Medium soil moisture pH high to moderate (6–7.5) Moderate erosion Agriculture and fallow land with Sparse forest	Good land for arable farming under proper farm management practices
Marginally suitable	6514	16	12–20° slope Shallow soils (30–50) with thin soils at a places Loam soil texture Low WHC Less soil moisture Availability of nutrients are low due to steep slope Terrace farming and fallow land Scrub land on shallow soil and moderate slope	Medium suitability for agriculture under careful farm management. Only terrace cultivation is possible. There is need to protections of land from intensive erosion and drainage
Not suitable	15,798	38	Thin soils and rocky lands with precipitous slope Very low MWHC Dry soil Highly eroded land Barren land Dense forest Scrub land on steep slope	These lands are not suitable for agriculture. Areas under settlement, open rocks, road, dense reserve and protected forest are not considered for agriculture
Total	42,010	100		

levels but also for enhancing the accuracy of output map. Ground reference points were selected from study area using GPS technique and verified using classified data. Some points were mismatched to classified data and reference data. Therefore, the process of LSA were revised i.e. ranks and weights to achieve optimal results.

The overall accuracy of the classified map is estimated about 90.38% with variation in producer's and user's accuracy. The highly suitable lands and not suitable lands are estimated 97.36% and 97.67% accuracy for producers and 90.24% and 95.45% for users, respectively. In the present study, thematic maps i.e. EC, N, P, K and SOC were prepared using IWD interpolation techniques and used with satellite data in weighted overlay techniques. Therefore, some patches of moderately suitable lands are intermixed with marginally suitable lands shows lesser accuracy i.e. 83.87% and 88.63% for producers and 89.65% and 85.71% for users, respectively (Table 8).

4. Results and discussion

The weights of selected criterion calculated in AHP analyses and assigned scores of sub-criterion were used in WOA to map the LS for agriculture. LS for agriculture categorized into four classes i.e. highly suitable, moderately suitable, marginally suitable and not suitable.

4.1. Highly suitable

About 17% land of the reviewed area was classified into the class, 'Highly suitable' for agriculture (Fig. 15) with 9.10% under agriculture and 10.37% fallow lands. The lands classified into this class have gentle to moderate slopes, deep loam soils with higher water retention capacities and moisture, normal pH (Table 9). The fallow lands classified in this class can be converted into agricultural lands, if irrigation facilities and required financial supports are available. However, these lands show minor limitations like moderate to marginal soil nutrients i.e. N, P and K which require external inputs for optimum agricultural production.

4.2. Moderately suitable

Moderately suitable lands for agriculture were estimated about 29% of reviewed lands (Fig. 15). These lands have stiff slopes, loam soil with moderate depth, water retention capacities, soil moisture as well as erosion (Table 9). These lands are fallow, under grasses and very sparse forests and require additional inputs as well as efforts for intensive farm management practices for agriculture.

4.3. Marginally suitable

Only 16% of reviewed lands are classified into the suitability class, 'marginally suitable' (Table 9; Fig. 15). These lands have shallow soil with steep slope, low water retention capacities, less soil moisture and lesser nutrients as well as more erosion activities. Generally, more than 12° slopes are not considered for agriculture activities. Some of the patches on steep slopes with deep soils and more moisture can be terraced for cultivation of crops like *Nagali, Varai, Khurasani*, etc. These lands need to be protected from intensive soil erosion.

4.4. Not suitable

Precipitous slopes (<30°) with rocky surface, barrenness, thin and dry soils are classified into the class, 'not suitable' (38%) for agriculture (Table 9 and Fig. 15). The study area is located in Eastern part of the Western Ghats of Maharashtra (India) and considered environmentally sensitive zone which is to be protected and conserved. Therefore, agricultural activities cannot be carried out on medium to dense forest lands.

5. Conclusions

1. Remotely sensed IRS P6 LISS-IV satellite data sets are useful for detection of suitable lands for agriculture
2. The GIS based multi-criteria evaluation technique is useful for LSA in hilly zone.
3. Twelve criterion i.e. slope, LULC, soil depth, MWHC, moisture, texture, erosion, pH, EC, SOC, N, P and K were selected for LSA for agriculture in the present study.
4. Correlation analyses are helpful for robust judgment of ranking the criterion for LSA.
5. Ranks of criterion were determined based on expert opinion, literature survey and correlation analyses.
6. Slope, LULC, soil depth, soil texture, soil moisture and soil erosion show higher influence on agriculture in the region.
7. The nutrients like N, P and K are available at marginal to moderate level required external inputs for agriculture.
8. About 17% of reviewed land is highly suitable, 29% is moderately suitable, 16% is marginally suitable and 38% is not suitable for agriculture.
9. Highly suitable lands have no significant limitations for existing cropping pattern i.e. rice with possibilities of intensive agriculture, if irrigation provided.
10. Moderately suitable lands are also suitable for agriculture but proper farm management required.
11. Marginally suitable lands shows medium suitability for crops like *Nagali*, *Varai* and *Khurasani* with requirements of terracing, additional inputs like fertilizers, protection from intensive run off and erosion, etc.
12. Areas of steep slopes, very thin soils, open rocks, dense reserve and protected forests, settlements, roads, etc. are not suitable for agriculture.
13. The moderately and marginally suitable lands have estimated lesser producer's (84% and 89%) and user's (90% and 86%) accuracy than the producer's accuracy (97.36% and 97.67%) and user's accuracy (90.24% and 95.45%) of highly suitable lands and not suitable lands.

The methodology formulated in this study can be an efficient tool for rapid assessment of LS for agriculture activity in hilly zones.

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