



Integrative approach of RS and GIS in characterization of land suitability for agriculture: a case study of Darna catchment

Rajendra Bhausaheb Zolekar¹

Received: 30 January 2018 / Accepted: 7 December 2018 / Published online: 18 December 2018
© Saudi Society for Geosciences 2018

Abstract

Land elements like slope, soil depth, land use/land cover, water holding capacity, soil texture, soil erosion, elevation, potential of hydrogen, etc. determine the suitability for agriculture. Land suitability analysis is a one of the methods of assessment of detecting inherent capacities, potential and suitability levels of the lands for agriculture, and was utilized with the same land elements in this study. A multi-criterion decision making approach using IRS P6 LISS-IV satellite dataset within a GIS environment was used to identify suitable areas for agriculture in the Darna catchment. Experts' opinions, literature review, and correlation technique were used to decide influencing criteria, assign scores to sub-criteria, and judgment formation in pairwise comparison matrix. All thematic layers of criteria were integrated with each other in GIS using the weighted overlay technique and generated agriculture suitability map into four classes according to FAO. About 23% of the area is under agriculture in the study region. This area can extend up to 69% under agriculture converting fallow land, scrub land, and sparse forest according to soil qualities with suitability levels, i.e., highly suitable (19%), moderately suitable (16%), and marginally suitable (34%). About 31% (19,219 ha) of reviewed area are classified in the class permanently "not suitable" for agriculture. Moderately and marginally suitable land requires the irrigation facility for efficient agriculture. This study emphasizes that about 46% area has potential as agriculture land and it will help improve the financial condition of the farmers.

Keywords Land suitability · Agriculture · Geographical information system · Analytic hierarchy process · Weighted overlay analysis

Introduction

Land is a potential source of natural resources, i.e., soil, water, nutrients, minerals, etc., for environmental services (Bhagat 2012). These elements determine land suitability (LS) for agriculture (Bandyopadhyay et al. 2009), settlement (Soltani et al. 2012), watershed management (Steiner et al. 2000), etc. Nowadays, agronomy is facing several problems like soil degradation, water logging, groundwater depletion (Deshmukh and Aher 2016), increase in surface runoff, productivity losses, etc. (Barah 2010). Consequently, fertile land is converted into fallow and barren land and results in low productivity. Land degradation

is one of the most important global environmental issues related to agriculture (Ravi et al. 2010). About 2.6 billion population depends on agriculture. Soil degradation moderately or severely affects 52% of the land used for agriculture (WMO 2005). Due to this problem, 1.5 billion people are directly affected. Starvation and malnutrition affect about 14.9% people of developing countries and 1.4% people of developed countries (FAO 2012). Hence, proper management and planning in agricultural land use is essential to solve the problem (Elsheikh et al. 2013). Several studies have been carried out for land suitability analysis (LSA) (Shalaby et al. 2006; Perveen et al. 2007; Bandyopadhyay et al. 2009; Elsheikh et al. 2013; Akinci et al. 2013) for sustainable land management (SLM) (Dumanski 1997). LSA is a method of detecting inherent capacity of the land, suitability levels, and potential sites for agricultural purpose. It is a fundamental step in SLM. It measures the degree of land appropriateness. LSA can solve problems related to land to enhance land efficiency and productivity and meet the needs of growing

✉ Rajendra Bhausaheb Zolekar
raj4mezolekar@gmail.com; rajzolekar@rediffmail.com

¹ Department of Geography, K.V.N. Naik Shikshan Prasarak Sanstha's Arts, Commerce and Science College Nashik, Nashik, Maharashtra 422002, India

population. Therefore, the present study has been focused on LSA for agriculture in Darna catchment for SLM.

The criteria like slope, land use/land cover (LULC), soil depth, soil texture, SM, soil nutrients, soil erosion, etc. are used for agricultural SLM. These parameters have not similarly influenced agriculture (Akinci et al. 2013). The influence and affluence of these parameters differ according to land qualities. Shalaby et al. (2006), Olayeye et al. (2008), Bandyopadhyay et al. (2009), Foshtomi et al. (2011), Mustafa et al. (2011), Akbulak (2010), Feizizadeh and Blaschke (2012), and Bojorquez-Tapia et al. (2001) have used similar parameters, i.e., slope, drainage, soil depth, LULC, texture, elevation, EC, OC, pH, N, P, K, etc. for agricultural LS. But some of these researchers have also considered additional climatic parameters like temperature, rainfall, moisture, humidity, etc. (Olayeye et al. 2008; Feizizadeh and Blaschke 2012; Wang 1994; Feizizadeh and Blaschke 2012). D'haeze et al. (2005) have mentioned criteria such as drainage, slope, soil depth, soil texture, organic carbon, topsoil stoniness, sub-soil stoniness, and pH for Robusta coffee in the Dak Gan region. Environmental components such as climate, soil, and topography at different spatial and temporal resolutions have been considered for identifying suitable areas for Oat in Central Mexico (Ceballos-Silva and López-Blanco 2003a). Previous literature shows that criteria like slope, LULC, soil depth, soil texture, maximum water holding capacity (MWHC), elevation, soil erosion, and pH have been frequently used for the study of agricultural land suitability in hilly zone. Therefore, similar standard parameters are considered in the present study.

Most of the researchers in the study of LSA have used geographical information system (GIS) based multi-criterion evaluation (MCE) technique. MCE of LS have considered selected criteria in decision making processes (Joerin et al. 2001; Wang et al. 1990; Akinci et al. 2013) to find solutions for different problems related to land with multiple alternatives (Jankowski 1995). GIS is useful to analyze the multiple geo-spatial data with higher flexibility and precision in 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; Garcia et al. 2014; Yalaw et al. 2016a, b) in complex problems of land management with prioritized alternatives (Malczewski 2006). These techniques are widely used for LSA to detect the potential land for agriculture (Ceballos-Silva and López-Blanco 2003a; Ceballos-Silva and López-Blanco 2003b; Akinci et al. 2013), 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 like agriculture, settlement, watershed, etc. AHP determines the weight of influence in certain land use using 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 elicited expert opinions to select the criteria for LSA. Therefore, MCDM based on AHP technique has been used in this exercise to detect the LS for agriculture in hilly zones using the influencing criteria suggested in expert opinions and previous literature.

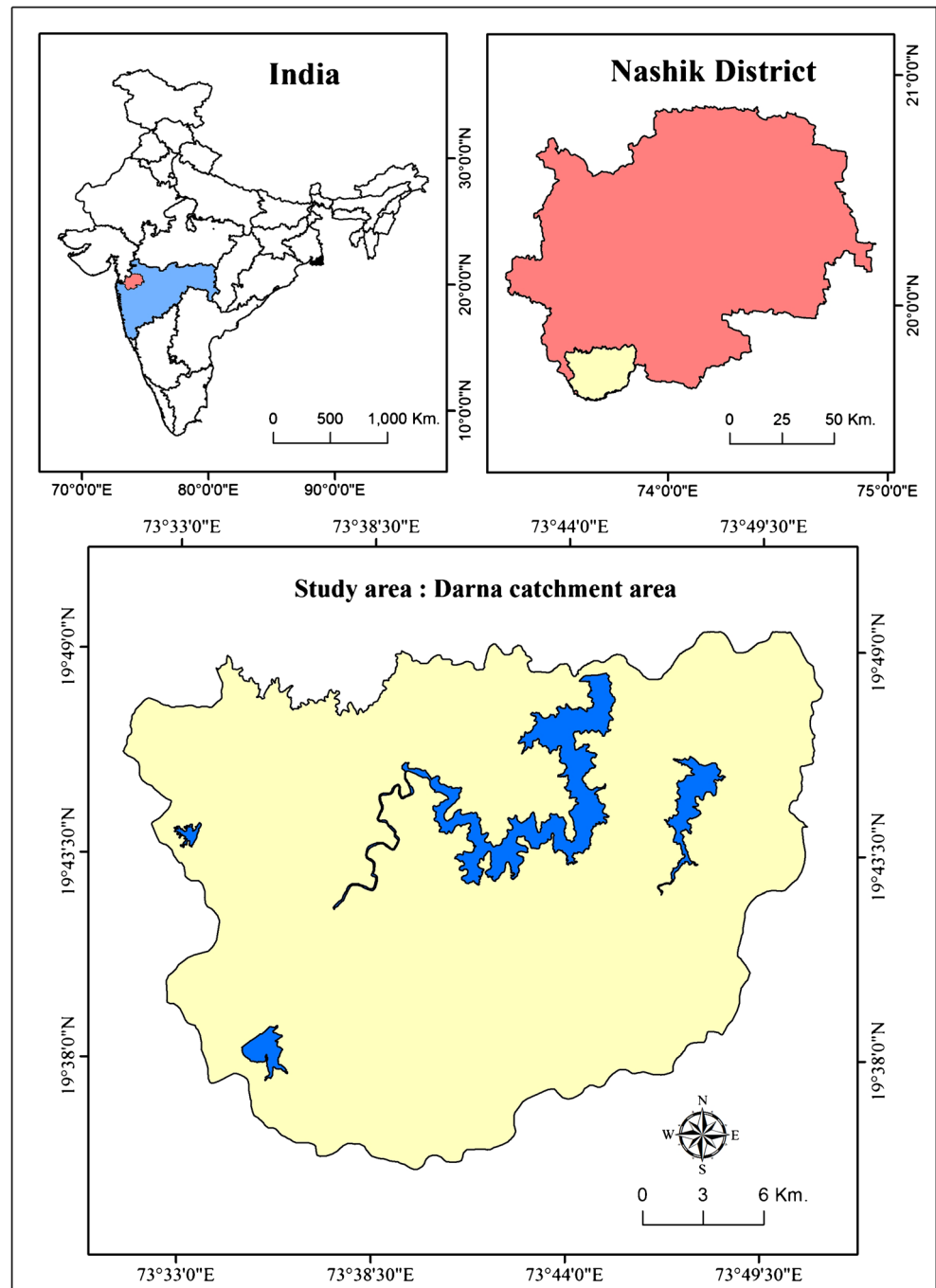
Study area

The study area is the part of Eastern slope of the Western *Ghat* of Igatpuri Tahsil in Maharashtra (India) and covered by catchment area of Darna River. It lies between 19° 35' 00" N to 19° 49' 30" N latitudes and 73° 31' 30" E to 73° 52' 15" E longitudes distributed in upstream (65,123 ha) in Darna River (Fig. 1). River Darna is a right-bank tributary of the Godavari. The Kadva is the right-bank sub-tributary of the Darna and the Waki, the Unduhol, and the Valdevi are left bank sub-tributaries. The Darna dam is constructed on the River Darna near Nandgaon village in Igatpuri Tahsil. The rainfall varies from 3178 mm at Western boundary to 1435 mm at Eastern border. The slope also varies from precipitous (West) to gentle (East). Loam soil texture with deep soil has been observed on a gentle to moderate slope along Darna basin at Eastern side and most of the Western areas are covered by thin and shallow soils with steep to precipitous. Parent rock is observed at western side of the study region due to steep to precipitous slope. The deep and moderately deep soils are suitable for agriculture activities. Agriculture is the main economic activity and rice is the dominant crop in the region. About 41% of the total population of the region is classified as tribal, i.e., *Mahadevколи* with literacy rate of about 67% (Census of India 2011).

Data and methodology

In order to detect the suitable land for agriculture of Darna basin, mainly physical parameters like slope, LULC, soil parameters such as depth, texture, MWHC, elevation, erosion, and pH have been assessed on the basis of expert opinions and literature review using GIS-based MCDM approach. The AHP is one of the MCDM tools which is flexible and robust and it helps to solve complex decision making problems. Therefore, the technique has been used for agricultural LSA in this study in the following five steps: (1) selection of criteria, (2) weight calculation to criteria using pairwise comparison matrix (PCM), (3) score determination to sub-criteria, (4) weighted overlay analysis, and (5) agriculture LS map (Fig. 2).

Fig. 1 The study area: Darna catchment in Igatpuri Tahsil



Database

The required data have been acquired from the primary as well as secondary sources. The satellite data, i.e., IPS 6-LISS IV, and topographic maps, i.e., relief, drainage, slope, elevation, soil texture, erosion, etc., have been acquired from different Government offices.

The topomaps (1976), soil texture, and soil erosion maps (1996) have been published on 1:50,000 and 1:500,000, respectively. The topomaps (47 E/9, 10, 13, 14) have also been

acquired from Survey of India (published, 1976) for the preparation of maps like relief, drainage, and slope (Table 1). Soil texture and soil erosion maps (1996) have been published on 1:50,000 and 1:500,000, respectively and procured from the National Bureau of Soil Survey and Land Use Planning Shankarnagar, Nagpur. Digital topographical maps have been used to generate digital elevation model (DEM) which was accordingly used to prepare elevation map.

The researchers like Bojorquez-Tapia et al. (2001), Shalaby et al. (2006), Srdjevic et al. (2007), Bandyopadhyay et al.

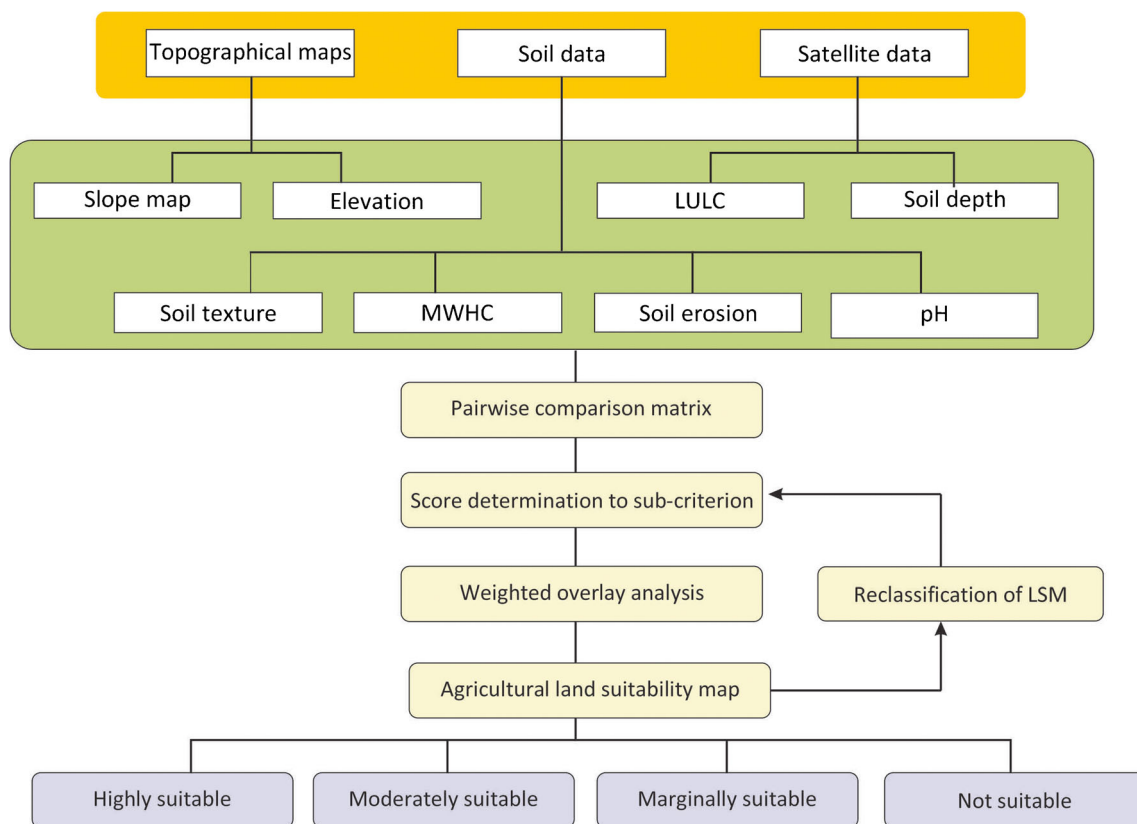


Fig. 2 Schematic preparation and LSA

(2009), Mustafa et al. (2011), etc. have widely used moderate resolution satellite data, i.e., TM (30 m), ETM+ (28.5 m), IRS-1D LISS-III (23 m), SPOT 5 (10 m) in LSA for different purposes. However, Bhagat (2012) and Zolekar and Bhagat (2014) have reported that high-resolution satellite datasets achieve better accuracy for agriculture purposes especially in hilly zone. Therefore, the high-resolution satellite data, i.e., IRS P6 LISS-IV (Path-095 / Row-059) dated 21 November 2013, have been procured from the National Remote Sensing Centre, (NRSC) Hyderabad (India) and were used for LSA in the present study. The image processing software, i.e., ERDAS (Earth Resources Data Analysis System) IMAGINE 2013, has been used for geometric correction using ground control points (14) from topographic maps to geocode the thematic map (TM) image and the root square mean error (RSME) was less than 0.4 pixels

which is acceptable. The RSME over 0.5 pixels is not acceptable (Lunetta and Elvidge 1998). The procured satellite image was cloud free and corrected atmospherically to obtain error free data. The data are available in three spectral bands, i.e., band 1 (green), band 2 (red), and band 3 (NIR). The spatial resolution of this datasets is 5.8 m with 10 bit radiometric resolution and 23 km swath width.

The field work was carried out to collect the information about LULC, soil depth, soil sample, and agricultural productivity with the help of global positioning system (GPS). Stratified random sampling method was used for collection of soil sample and agricultural productivity data. The samples (64) have been collected (April, 2017) on the basis of slope and soil depth. These samples were analyzed in laboratory to detect physical, i.e., MWHC and chemical properties, i.e., pH.

Table 1 Data base with acquisition methods

Data	Acquisition method	Use
Topographic maps: 47E/9, 47E/10, 47E/13 and 47E/14	Survey of India	To prepare of relief, drainage, and slope maps
Soil data	Laboratory analysis and Maharashtra Remote Sensing Application Centre (M.R.S.A.C.), Nagpur	To assess the soil qualities, i.e., MWHC, soil erosion, and pH
Satellite data: IRS P6 LISS-IV	NRSC, Hyderabad	To prepare the maps, i.e., LULC, soil depth, SM, etc.
Experts' opinions	Literature survey	To select the criteria, assign the scores to sub-criterion, and calculate the weight of criteria

RS data were loaded, processed, and analyzed in ERDAS and GIS software for the preparation of maps like slope, drainage, TIN, LULC, etc.

Criteria

Land productivity varies according to physical elements such as slope, soil depth, erosion, texture, etc. (Datye and Gupte 1984). Several studies have used criteria like slope, LULC, soil depth, soil texture, SM, soil nutrients, soil erosion, primary nutrients, i.e., N, P, K, etc., and are commonly used for LSA for agriculture. The composite effect of these parameters determines the potential of land for agriculture (Bandyopadhyay et al. 2009). These parameters influence agricultural yields. There is significant relationship between slopes and soil qualities with productivity of crops (Akinici et al. 2013). Therefore, these parameters are considered for LSA for agriculture on the basis of literature survey and local physiographic condition. The assessment of physical criterion provides the information about the inherent capacity of land for agricultural suitability.

Slope

Slope is a major physiographic aspect that influences on agriculture directly or indirectly in hilly zone. The soil characteristics like soil depth, texture, erosion, etc. vary according to slope (Akinici et al. 2013). Slope is positively correlated with soil erosion and negatively with soil depth (Table 2). The development of the soils depends on slope. Therefore, Survey of India (SOI) toposheets, i.e., 47 E/9, 10, 13, 14 of 1:50,000 scale with 20 m contour intervals have been used for preparation of slope map in different slope categories. About 5% reviewed land is good, 26% fair, 26% moderate, 23% average, and 20% land poor (Bandyopadhyay et al. 2009) (Fig. 3).

Soil depth

Fertile and deep soils are potentially good for crop growth. Water-storing capacity, SM (Akinici et al. 2013), distribution of nutrients and effective root zone, infiltration rate (Rabia

2012), etc. vary according to the soil depth. It is negatively associated with slope. The low levels of slope are observed in high soil depth with more MWHC and higher level slopes are observed in low soil depth with less MWHC in the study area. Table 4 shows that agriculture productivity increases with increase in soil depth and vice versa. Therefore, soil depth is considered to be an important criterion for agriculture LS.

Soil depth map was prepared in GIS software, i.e., ArcMap 10, with the combined data of surface slope, LULC, experts' opinion, and field data, i.e., correlation analysis (Zolekar and Bhagat 2015). The correlation analysis shows negative relationship between slope and soil depth. Therefore, steep to precipitous slopes are classified into thin and shallow soils and gentle to moderate slopes are classified into deep to moderate deep soils. However, some of the patches of rocky land have been observed on gentle to moderate slopes. Therefore, with the help of LULC map area under rocky land are merged into thin soil. The present investigation shows that the scrub land is observed in shallow soils and also classified in the same class. The topography of the region is undulating and erosion activities are dominant due to heavy rainfall. Consequently, some patches of agricultural and fallow land are converted into barren land. Hence, it is merged into shallow soil. Deep soils are found at foothills where dense forest is observed. Therefore, forest areas from LULC map are shown by moderately deep soils. Besides this, the expert opinions have also been taken into the consideration for the preparation of soil map. About 22% of TGA have deep soils distributed in narrow track with gentle and moderate slope near Dama dam. Moderate (10%) and marginally (23%) deep soils are distributed on steep to stiff slopes. About 15 and 30% reviewed land is observed to have shallow and thin soils, respectively (Fig. 4).

Land use/land cover

LULC plays an important role in environmental assessment related to environmental issues and themes (Iqbal and Khan 2014). It also indicates the distribution and characteristics of land like settlement, road, agriculture land, fallow land, barren land, rocky land, vegetation cover (dense, sparse, etc.), etc.

Table 2 Correlation matrix

	PH	MWHC (mm)	Elevation	Slope	Depth	Rainfall	Production
PH	1	-.028*	0.36**	0.21	-0.25*	0.19	-0.22
MWHC		1	-0.67**	-0.65**	0.95**	-0.22	0.77**
Elevation			1	0.46**	-0.69**	0.30**	-0.57**
Slope				1	-0.63**	0.29*	-0.71**
Depth					1	-0.23*	0.79**
Rainfall						1	-0.29*
Production							1

**Correlation is significant at 0.01 level (two-tailed)

*Correlation is significant at 0.05 level (two-tailed)

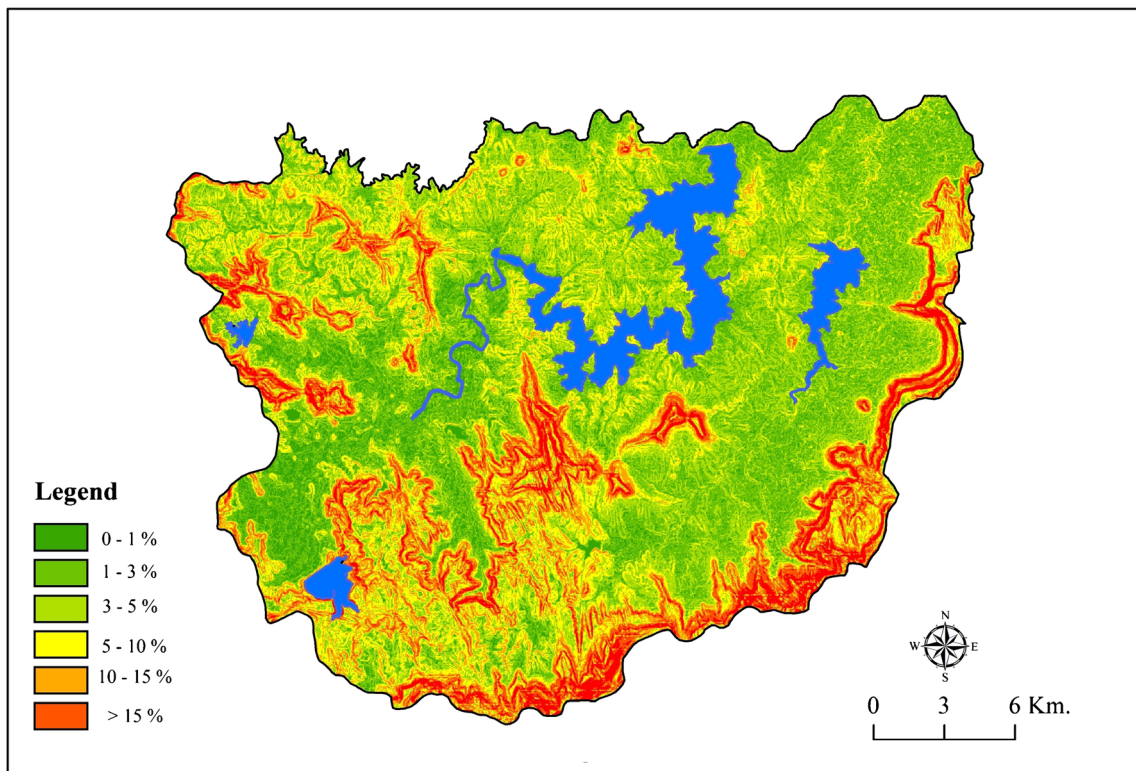


Fig. 3 Distribution of slopes

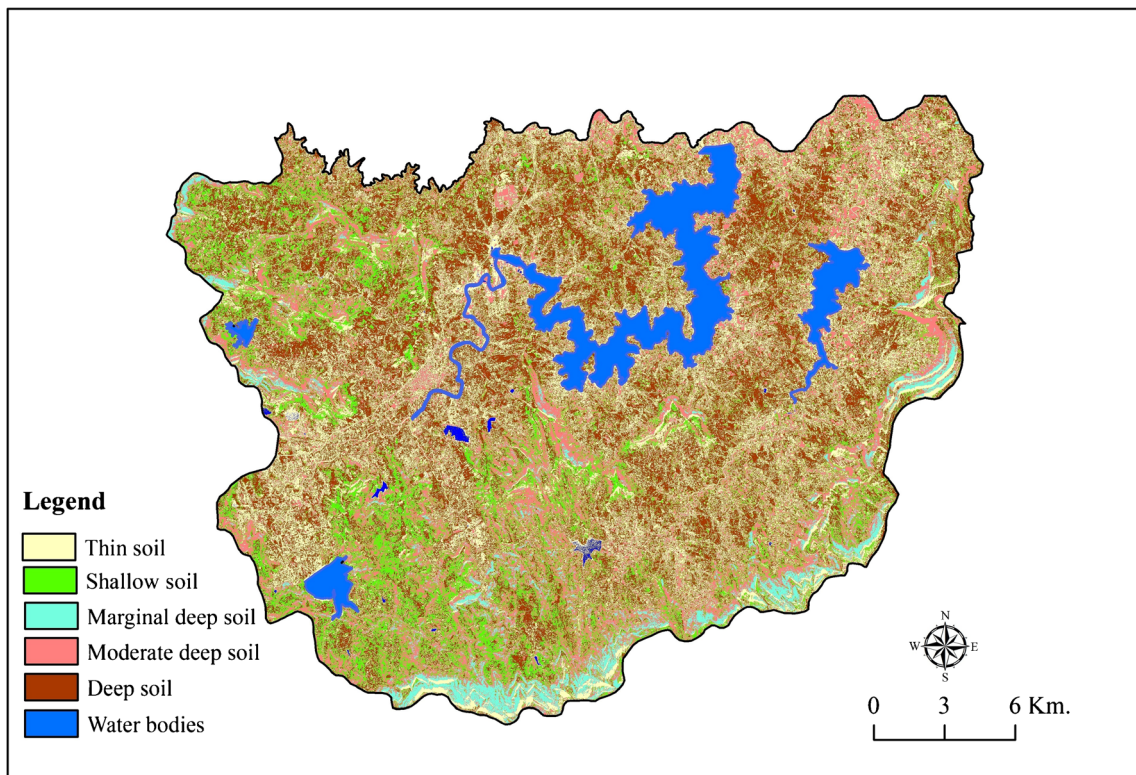


Fig. 4 Distribution of soils

Therefore, the researchers like Shalaby et al. (2006), Bandyopadhyay et al. (2009), etc. have used LULC for land use assessment in LSA. The IRS P6 LISS-IV satellite image was classified using supervise classification method, i.e., Bayesian maximum likelihood. The training sets of nine dominant classes, namely water body (5%), agriculture (23%), fallow land (6%), barren land (25%), settlement (2%), scrub land (14%), dense forest (3%), sparse forest (20%), and rocky land (2%), were identified from the watershed using the ERDAS-Imagine software (Fig. 5). From the land use point of view, present agriculture land is classified under highly suitable category. Fallow land has potential for agriculture, but is not presently used under for it. Therefore, this class of land has been classified as marginally suitable for agriculture. Some classes like settlement, barren land, water bodies, and rocky land are permanently not suitable for agriculture. Therefore, these classes are categorized into the ones that are not suitable for agriculture purposes. Most of the area under dense forest in the study region is environmentally protected zone and not permissible for agriculture activity. Therefore, this class of land has also been classified as “not suitable.”

Soil texture

Texture is the composition of soil particles consisting of sand, silt, and clay. It controls the structure, fertility, and water availability for crop production (Mojid et al. 2009). Availability of

water, minerals, and nutrients depends on soil texture. It is important for plant growth.

The researchers like Olayeye et al. (2008), Jafari and Zaredar (2010), Mustafa et al. (2011), etc. have used soil texture thematic map for assessment of LSA for agronomy purposes. Therefore, soil textural classification has been studied in the present study for LSA.

Loam soil is the most important soil type in the region and it is composed of clay, silt, and sand. FAO (2006) has reported that loam soil is the highly suitable soil for enhancing agricultural yield. Loam soils are observed on moderate to gentle slope and steep slopes in the study region (Fig. 6).

About 26% of TGA has loam soils and the same distributed on steeply sloping and highly dissected escarpments of the study area. Due to heavy rainfall, soil particles of loam soils are washed out from steep slope toward the streams and accumulated on rocky terrain. It gets covered by scrub and bushes. Therefore, these loam soils on the rocky terrain land are not suitable for agriculture. About 74% of TGA of loam soils is also distributed on moderate to gentle slopes in the study region and highly suitable for agriculture.

Maximum water holding capacity

MWHC of soils determines soil depth, leaching process of nutrients and pesticides, water availability, cropping pattern, irrigation facilities, etc. Soil depth, soil texture, organic contents,

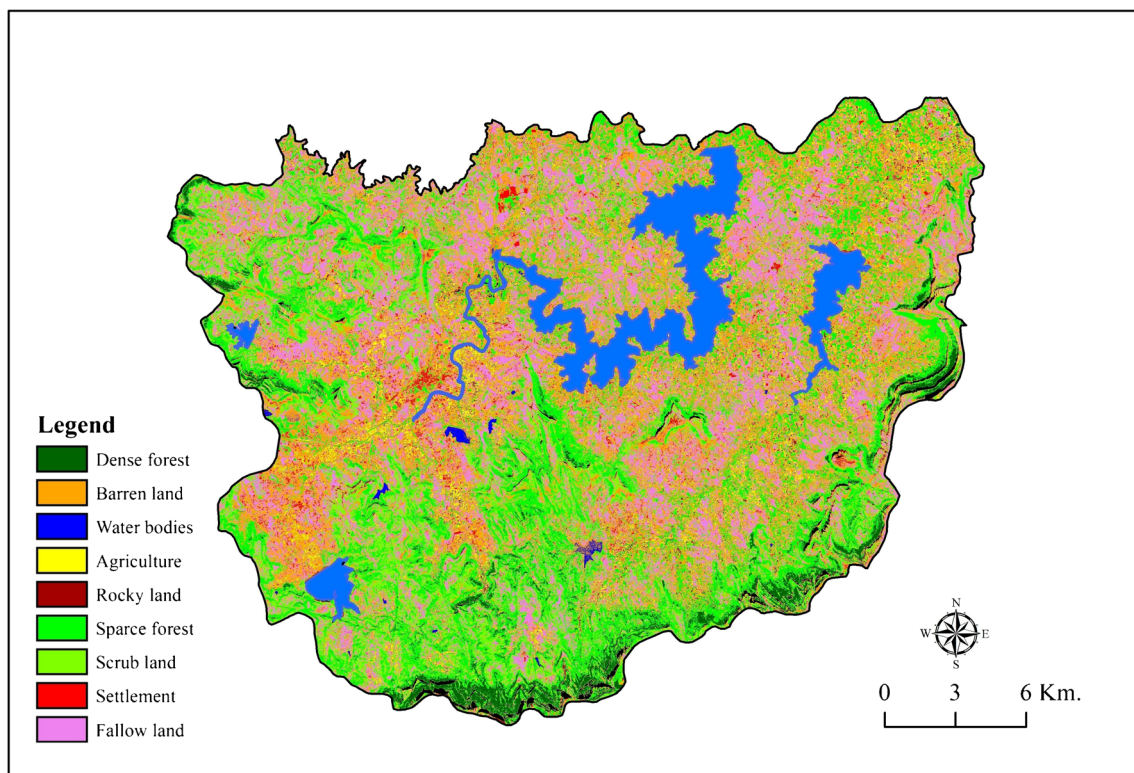


Fig. 5 Land use/land cover

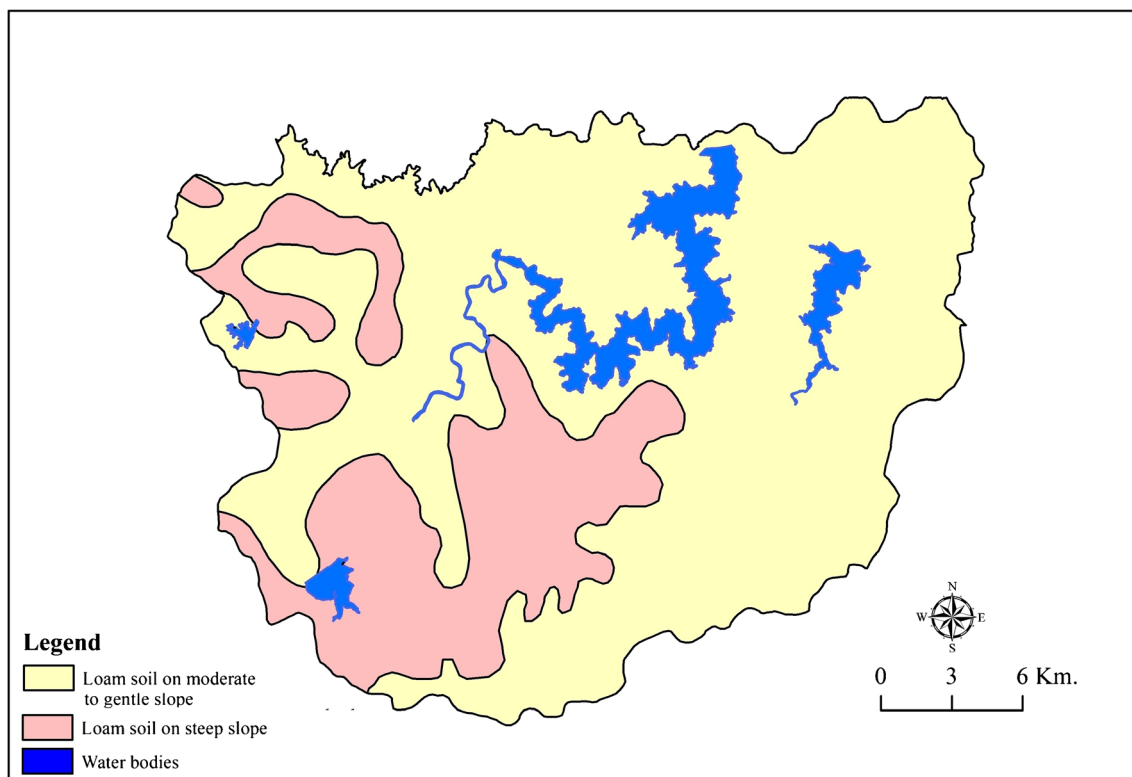


Fig. 6 Distribution of soil texture

etc. influence MWHC (Bhagat 2014). Sixty-four soil samples have been collected from the study region with 4 fields selected basis on soil depth, i.e., shallow soil, marginal deep soils, moderate deep soils, and deep soils. Equal samples (16) were collected (April, 2017) from each field and analyzed in laboratory.

The average values of MWHC for each class of soil depth (thin soil and shallow soil, 43 mm MWHC; marginal deep soil, 203 mm MWHC; moderate deep soil, 295 mm MWHC; and deep soil, 425 mm MWHC) were calculated. These classes are reclassified into the water holding capacity classes' viz. very low (43 mm MWHC), low (203 mm MWHC), moderate (295 mm MWHC), and high (425 mm MWHC) covers 22% (very low MWHC), 10% (low MWHC), 38% (moderate MWHC), and 20% (High MWHC) of TGA accordingly (Fig. 7).

Elevation

Topographical factor, i.e., slope and elevation, is a controlling factor in agriculture. Elevation with slope determines the microclimate, accumulation of soils, large-scale spatial distribution, and pattern of crops (Jin et al. 2008). Temperature decreases with increasing elevation and it plays an important role in growth of crops if sufficient water is available. It varies with topographical factor, i.e., slope, elevation, etc. Temperature controls the potential evapotranspiration (PE), humidity, soil temperature, SM, etc. Therefore, it affects the plant growth through photosynthesis and respiration, germination, flowering, growth

of root, fertilizer intake capacity, etc. Consequently, the crops on the lower altitude grow rapidly and the ones on higher altitude grow slowly (Akinci et al. 2013). All these elements determine the quality and quantity of crop production in the region. Therefore, elevation is considered for assessment of LS (Fig. 8).

Soil erosion

Morphometric activities are responsible for erosion in the hilly zone (Krishnamurthy 1997). Due to erosion activity, fertile top soil layer, nutritional elements, and organic matter are reduced. It affects the physical, chemical, and biological properties of soil (Akinci et al. 2013), resulting in the decreased productivity. Therefore, soil erosion map has also been considered for LSA.

Soil erosion map has been procured from M.R.S.A.C., Nagpur and used for LSA. The study area is classified into two different categories of erosion, i.e., slight erosion (35%) and moderate erosion (65%) (Fig. 9).

Potential of hydrogen (pH)

Soil pH provides information about the solubility and phytotoxicity of elements for crop suitability assessment (Mustafa et al. 2011). It affects directly the microbiological activities. Crop growth, crop yields, nutrients availability, etc. vary with pH (Thompson and Troeh 1973). Therefore, to understand the soil pH, samples has been collected from fields work using

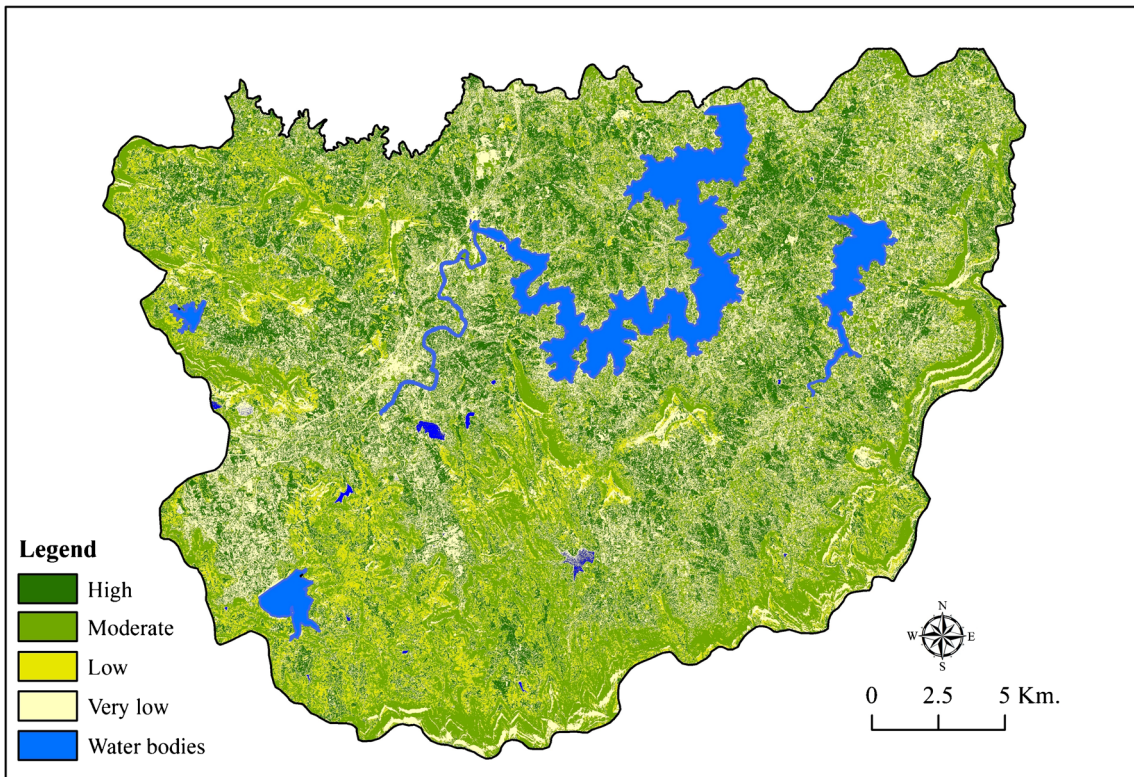


Fig. 7 Maximum water holding capacity

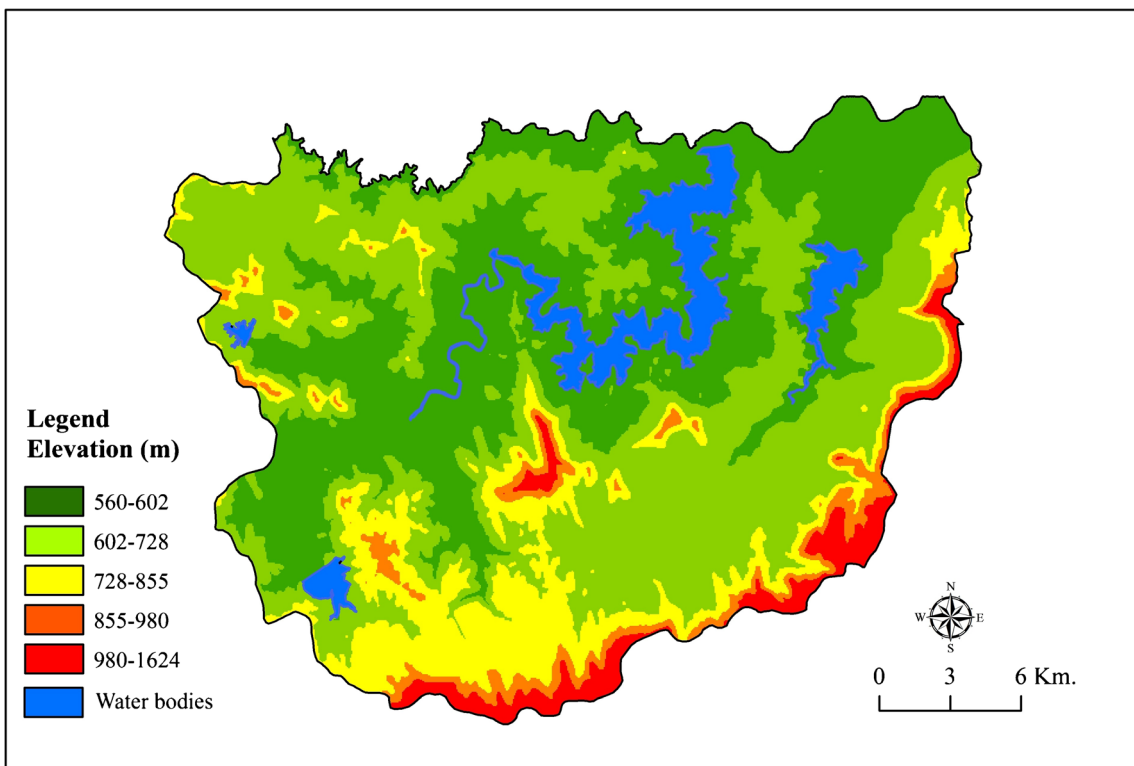


Fig. 8 Elevation

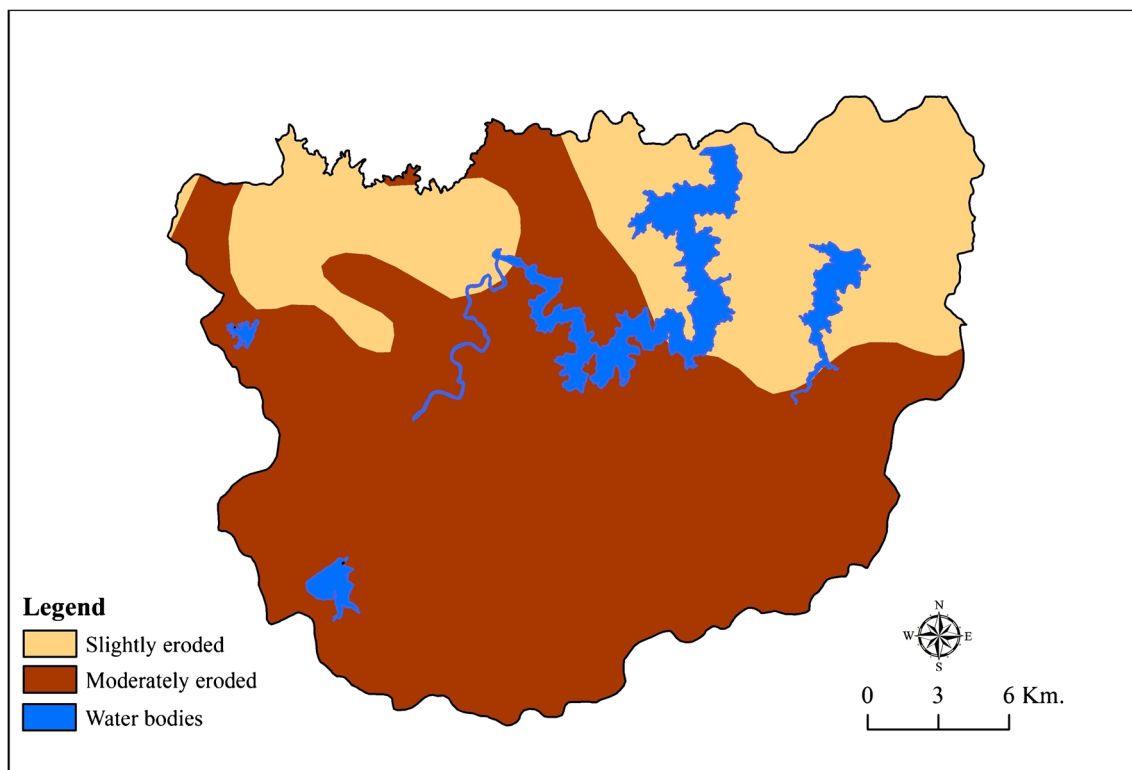


Fig. 9 Distribution of soil erosion

purposive sampling method and analyzed in laboratory to show spatial distribution. The interpolation technique, i.e., moving window kriging, has been applied for the preparation of the pH map which was classified into different classes.

The optimum pH range for most plants is between 5.5 and 7.5 and the same range is observed in the region. pH below 7 is acidic and above 7 is alkaline. The average value of pH in the study area is 6.7 and highly suitable for different crops. The map shows that about 45% area is highly suitable for agriculture and only about 20% of the area is moderately suitable for agriculture considering the pH (Fig. 10).

GIS-based multi-criterion decision making method

GIS-based MCDM method considers a number of criteria in decision-making process for different environmental issues. It is developed for solving spatial complex problems related to LSA (Malczewski 1999) and land use planning (Prakash 2003) for different purposes like agriculture (Ceballos-Silva and López-Blanco 2003a; Akinci et al. 2013; Garcia et al. 2014; Yalaw et al. 2016a), settlement (Soltani et al. 2012), water shade management (Steiner et al. 2000), etc. The role of the physical criterion is important in decision making process with MCE approach for LS. However, the weights of these criteria are not equal in LSA (Prakash 2003). Therefore, GIS-based MEC with AHP has been used for the determination of the weights of the criteria and scores of the sub-criteria. Perveen

et al. (2007), Mustafa et al. (2011), Feizizadeh and Blaschke (2012), Mokarram and Aminzadeh (2010), Mendas and Delali (2012), etc. have been using GIS-based MCE for weight determination for different criteria. In decision making process, all criteria are measured according to their level of importance in AHP technique. Therefore, GIS-based MCDM method, i.e., AHP, has been used for LSA in the present study.

Analytical hierarchy process

AHP is a method of MCDM approach which is developed by Prof. Thomas L. Saaty in 1970s. It is widely used for solving complex problems related to group decision making based on Mathematics and Psychology. Several researchers have been attracted to AHP. This method is based on weights of the criteria (Rabia and Terribile 2013) and is related to inconsistent judgments. It provides a measure of the inconsistency of the judgment of the respondents (Duc 2006). AHP decides the weights for different parameters using pairwise comparisons matrix (PCM) (Cengiz and Akbulak 2009; Yalaw et al. 2016a, b). This matrix is used to assign different levels of importance of criteria involved in LSA. The PCM is essential for judgment formation in AHP.

PCM was formed on the basis of the preference scale suggested by Saaty (1980) (Table 3) to express the relative importance between each two criteria (Akinci et al. 2013). The experts' opinion and literature review were used for formation

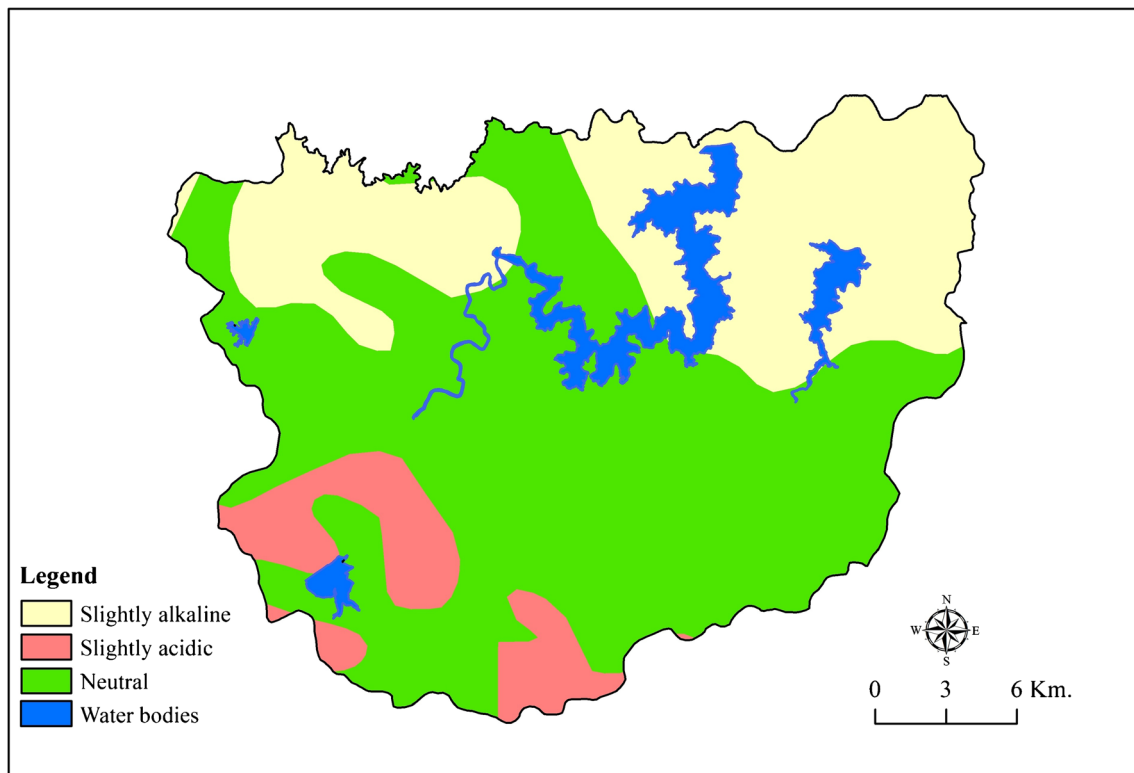


Fig. 10 Distribution of pH

of judgment between two criteria and the PCM was prepared (Table 4). Weights were calculated by normalizing the PCM. Normalized pairwise comparison matrix (NPCM) has been obtained by dividing the column elements of the matrix by the sum of each column. The row elements in the obtained matrix are summed and the total value is divided by the number of elements in the row (Akinci et al. 2013). NPCM was calculated using Microsoft Excel. In this way, weights were calculated for the selected criteria (Table 5).

The selected criteria together contribute significantly to study the LS for agriculture. However, influence of all criteria is not equal on agricultural suitability. Therefore, some of the

methods, i.e., expert opinions, correlation analysis, and literature review, were used in AHP for determination of weights of these criteria and score of the sub-criteria. AHP determines the weight of influence in certain land use using pairwise comparisons of parameters according to relative importance. Weights determine position or important level of parameters in hierarchy. Therefore, judgments were formed in PCM to calculate weights. Correlation technique has been used to understand the association between different variables for formation of judgments for different criteria. Judgments are reflected in PCM output. Consequently, the different criteria weights lead to remarkably different results.

Table 3 The fundamental scale for pairwise comparison (Saaty 1980)

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored and its dominance demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals	If activity i has one of the above numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	

Table 4 Pairwise comparisons matrix

Criteria	Slope	Depth	LULC	Texture	MWHC	Elevation	Erosion	pH
Slope	1/1	2/1	2/1	3/1	4/1	5/1	8/1	9/1
Depth	1/2	1/1	2/1	3/1	4/1	6/1	7/1	8/1
LULC	1/2	1/2	1/1	2/1	3/1	4/1	5/1	7/1
Texture	1/3	1/3	1/2	1/1	2/1	3/1	5/1	6/1
MWHC	1/4	1/4	1/3	1/2	1/1	3/1	5/1	6/1
Elevation	1/5	1/6	1/4	1/3	1/3	1/1	1/1	2/1
Erosion	1/8	1/7	1/5	1/5	1/5	1/1	1/1	1/1
pH	1/9	1/8	1/7	1/6	1/6	1/2	1/1	1/1

Correlation matrix and experts opinion show that the slopes and soil depths are directly associated to maximum parameters, i.e., water holding capacity of soils, elevation, and agricultural productivity (Table 2). Slope and soil depth shows higher influence on agriculture yield in mountain regions. Variations of soil depth are negatively associated with slope and positively associated with agricultural production (Table 2). The correlation analysis clearly brings out the importance of physical factors like slope and soil depth as major factor influencing agricultural yields. Therefore, PCM estimated highest weights to slope (0.29) and soil depth (0.25). The criteria, i.e., texture (0.11) and MWHC (0.9) vary by slope and soil depth with moderate influence. MWHC is positively associated with soil depth (0.95), agriculture production (0.77) and negatively associated with slope (-0.65) and elevation (-0.67). It has been considered for formation of judgments. Therefore, moderate weights were estimated for texture (0.11) and MWHC (0.9). Erosion is a limiting factor in agricultural activity which was assigned the last position. Therefore, a weight is very less (0.3) compared to other parameters.

The range of the calculated weights within 0–1, and their sum is equal to 1 (Malczewski 1999). The accuracy of calculated weights depends on consistency ratio (CR) (Eq. 1). CR measures logical inconsistency of the judgments and facilitate identification of possible errors. Judgment improvements depend on CR. Acceptable value of CR up to 0.10 (Saaty 1997). If the CR is greater than 0.10, then the judgments need to be revised. Calculated CR is 0.03, therefore these judgments' and weights are acceptable for LSA in the present analysis.

$$\text{Consistency ratio (CR)} = \text{CI/CR} \quad (1)$$

Determination of scores

The researchers in the field of LSA have assigned scores to sub-criteria on the basis of land qualities. In the present study, scores for sub-criteria were assigned based on experts' opinions, correlation analysis, and literature review related to LSA. The scores were assigned to the sub-criteria from 1 to 9. Higher score indicates higher influence of sub-criteria,

Table 5 Normalized pairwise comparisons matrix

Criteria	Slope	Soil depth	LULC	Texture	MWHC	Elevation	Erosion	pH	Weights
Slope	1	2	2	3	4	5	8	9	0.29
Soil depth	0.5	1	2	3	4	6	7	8	0.25
LULC	0.5	0.5	1	2	3	4	5	7	0.17
Texture	0.33	0.33	0.5	1	2	3	5	6	0.11
MWHC	0.25	0.25	0.33	0.5	1	3	5	6	0.09
Elevation	0.20	0.16	0.25	0.33	0.33	1	1	2	0.04
Erosion	0.12	0.14	0.2	0.2	0.20	1	1	1	0.03
pH	0.11	0.12	0.14	0.16	0.16	0.5	1	1	0.02

Maximum eigen value (k_{\max}) = 8.31086

$n = 8$

Consistency index (CI) = $(k_{\max} - n)/(n - 1) = 0.0444$

Random index (RI) = 1.45

Consistency ratio (CR) = CI/RI

CR = $0.0444/1.45 = 0.0314$

whereas lower score indicates least suitability for agriculture (Akinci et al. 2013; Elsheikh et al. 2013). The value 9 is considered to be the most suitable and 1 the least suitable. The scores for selected criteria were assigned, accordingly (Table 6).

Bandyopadhyay et al. (2009) have reported that slope shows negative relation with crop yield (Table 2). Therefore, scores 9 and 8 were assigned to good and fair slopes with deep to moderate deep soils respectively. Score 6 was assigned to moderate to average slopes with marginally deep soils. They are moderately suitable for agriculture. Score 1 was assigned to poor slopes with shallow and thin soils which is considered to be unsuitable for agriculture

(Table 6). The lower degree of slope is more suitable than the higher degree of slope.

Agriculture productivity is positively associated with soil depth (Table 2). It means that inherent capacity of land decreases with decrease in soil depth for agriculture purposes. Therefore, maximum score (9) was assigned to deep soil and minimum (1) was assigned to thin soils (Akinci et al. 2013) (Table 6).

Erosion work removes top fertile layer from steep to precipitous slopes due to heavy rainfall. Therefore, minimum score 1 was assigned to highly eroded land with steep to precipitous slopes and maximum score 9 was assigned to slightly eroded land (Table 6).

Table 6 Weights and score

Criteria	Weight	Influence (%)	Sub-criterion (with ranges)	Area (ha)	Score
Slope (°)	0.29	29	Good	3097	9
			Fair	15,871	9
			Moderate	15,981	6
			Average	14,449	6
			Poor	12,267	1
Depth (cm)	0.25	25	Deep soil	13,315	9
			Moderate depth	6438	7
			Marginal depth	14,315	6
			Shallow soil	9315	4
			Thin soil	18,282	1
LULC	0.17	17	Agriculture	14,711	9
			Fallow land	3606	8
			Sparse forest	12,945	6
			Scrub land	9112	4
			Barren land	16,527	1
			Dense forest	2009	1
			Settlement	1247	1
			Rocky land	1508	1
			Water body	3458	Restricted
			Texture	0.11	11
			Loam soils on steep slope	15,971	7
MWHC	0.09	9	High	13,315	9
			Moderate	6438	7
			Low	23,630	4
			Very low	18,282	1
Elevation (m)	0.04	4	< 602	18,315	9
			602–728	38,795	8
			728–855	3265	4
			> 855	1290	1
			Erosion	0.03	3
			Moderately eroded	40,383	7
pH	0.02	2	Slightly alkaline	21,282	9
			Slightly acidic	12,333	7
			Neutral	28,050	5

MWHC of soils increases with increase in soil depth and vice versa (Table 2). Therefore, similar scores were assigned to the classes of soils MWHC (Table 6).

Deep and fertile soils decrease with increase in elevation and vice versa (Table 2). Therefore, score 1 was assigned to higher elevation and score 9 was assigned to lower elevation (Table 6). Soil erosion removes top and fertile soils, therefore maximum score (9) was assigned to slightly eroded land and 7 was assigned to moderately eroded land. pH was classified into three classes, i.e., slightly alkaline, slightly acidic, neutral and were assigned scores 9, 7, and 5 respectively (Table 6).

Weighted overlay analysis

Agricultural LS has been extracted using weighted overlay analysis (WOA) based on MCDM. All raster maps are integrated with each other in GIS environment using WOA tool. It is a technique for applying a common scale of values to diverse and dissimilar inputs to create an integrated analysis (Malczewski 1999, 2004). The cell values of each input raster layer are multiplied by their weights (Cengiz and Akbulak 2009) (Eq. 2).

$$S = \sum_{i=1}^n w_i x_i \text{ (after Cengiz and Akbulak 2009)} \quad (2)$$

Where

S total LS score,
 w_i weight of LS criteria,

x_i sub-criteria score of i LS criteria,
 n total number of LS criteria.

After criteria weights and sub-criteria scores were selected to the related layers in the ArcMap 10, raster maps of selected criteria were overlaid using the WOA and a map was generated for agricultural LS. Then output raster map was divided into four classes (i.e., 9, 6, 4, and 1) depending on assigned scores of 1 to 9. Finally, these classes were reclassified according to the LS classification of Food Agriculture Organization (FAO), i.e., highly suitable, moderately suitable, marginally suitable, and not suitable (Fig. 11).

Accuracy assessment

Several researchers have used error matrix to accuracy assessment for comparison between output data (classified data) and ground truth data (reference data) (Zolekar and Bhagat 2015). Error matrix has been used to estimate the users, producers, and overall accuracy for accuracy assessment. It has not only been used for knowing accuracy levels but also for increasing the accuracy of output map. The accuracy assessment was carried out using 145 ground reference points from field using GPS technique and verified using classified data. Some ground reference points were mismatched to output data and reference data. Therefore, the process of LSA have been revised, i.e., ranks and weights of parameters to achieve precise results.

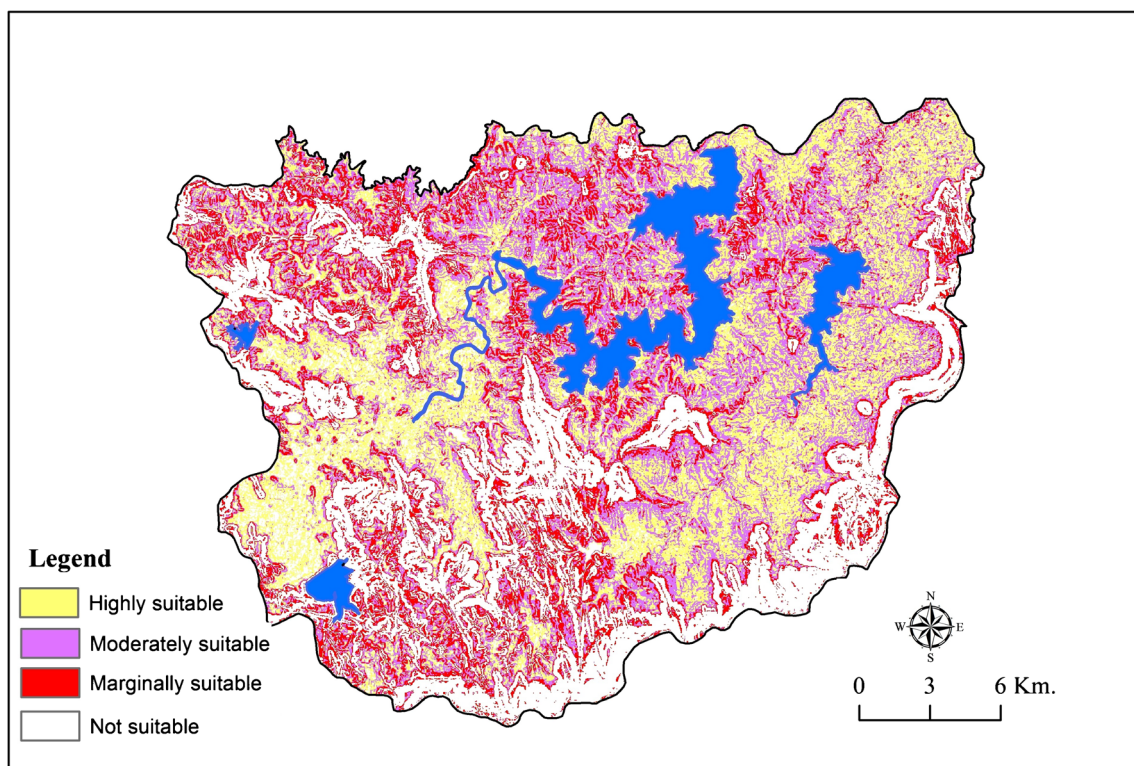


Fig. 11 Land suitability map for agriculture

Results and discussion

The present study has its basis in the FAO framework for land evaluation. The weights of selected criteria calculated in AHP using PCM and scores of sub-criteria were assigned in WOA to prepare the map of agricultural LS. Final LS map was generated in raster format. The pixel values in final output raster map have been reclassified into four classes values ranging from 1 to 9 where 9 represents highly suitable, 6 for moderately suitable, 4 to marginally suitable, and 1 represents not suitable for agriculture activity.

The present investigation shows that the role of all the criteria which determine the suitable land for agriculture depends on land quality and topography. Accordingly, the weights of the criteria have changed. As well as the impact of the slope in the highland region is seen in the order of priority of agricultural production. A more recent study (Akinci et al. 2013 and Sarkar et al. 2014) has reported that higher slopes influence on the highly suitable land for agricultural activities. It means that high slope with thin and shallow soils are limiting factors for agricultural development. Poor soil drainage, eroded land, higher surface slope, floodplains, etc. are the characteristics of unsuitable land for agriculture (Steiner et al. 2000). Demir et al. (2011) has conducted a similar investigation and parallel results were obtained in the evaluation of agricultural land suitability. Considering all these parameters, the results generated by AHP are that the slope has the largest weight for determination of LS in the study area with a value of 0.29 followed by soil depth and LULC with weight values of 0.25 and 0.17, respectively. On the other hand, pH has the smallest weight value of 0.02, followed by soil erosion and elevation with values of 0.03 and 0.09, respectively. In such circumstances, it can be stated that physical environment determine land potential for agriculture. Slope and soil depth are the most sensitive criteria in the hilly region according to PCM and it is statistically significant. It seems that variation of the results of the present investigation depends on calculated weights of criteria and assigned score to sub-criteria that were given based on the

experts’ opinion, literature review, and correlation analysis to different land characteristics.

The present study makes it clear that only about 23% existing area is under agriculture out of which about 19% (11,418 ha) of reviewed land was detected highly suitable for agricultural activity and no significant limitations were noted for that purpose. These forms of land have gentle to moderate slopes with less than 700 m altitude, deep loam soils, MWHC, and normal pH range. Out of the total existing agriculture land remaining, 4% was found in moderately suitable.

About 16% (9971 ha) of reviewed land was classified into the class “moderately suitable” (Fig. 11). The characteristics of these forms of land are fallow with stiff slopes, loam soil distributed on gentle to moderate slopes, moderate soil depth, moderate water retention capacities, and slight erosion. Additionally, 12% of land has been proposed for agriculture. Though there is some limitation of this land, it can be used for agricultural purposes with rainfed crops in rainy season. It will be beneficial to farmers to raise their income. It is also pertinent to mention that in the present study, additional inputs and efforts are required for farm management practices.

Marginally suitable land for agriculture was estimated to be about 34% (21,057 ha) of reviewed land (Fig. 11). These forms of land have shallow soil with steep slope, less water holding capacity, normal pH range, and terraced lands with deep soils can be used for agriculture but there is a need for protection from intensive soil erosion and drainage.

Permanently not suitable land for agriculture was estimated to be about 31% of reviewed area. These forms of land have settlement, roads, precipitous slopes, rocky land, barren land, thin and dry soils, etc. (Fig. 11). Steep to precipitous slope, higher altitude, and moderate erosion along with the shallow and thin soil of the study area were the affecting factors, resulting in an unsuitable agricultural land in this study. High slope, thin and shallow soils along with barren land of the study area were affecting factors, resulting in a low rate of highly suitable agricultural land in this study. Agricultural activities cannot be carried out in dense forest. The

Table 7 Error matrix: accuracy assessment

Classified classes	Reference class				Total sample	User’s accuracy (%)
	Highly suitable	Moderately suitable	Marginally suitable	Not suitable		
Highly suitable	34	2	1	0	37	91.89
Moderately suitable	0	27	2	1	30	90
Marginally suitable	1	3	34	1	39	87.17
Not suitable	0	0	2	37	39	94.87
Total sample	35	32	39	39		
Producer’s accuracy (%)	97.14	84.37	87.17	94.87		90.93

government has declared the study area to be environmentally protected zone. Therefore, the dense forests are not suggested for agricultural activities.

Land under agriculture can extend up to 69% converting fallow land, scrub land, and sparse forest according to soil qualities with suitability levels, i.e., moderately and marginally suitable. This study emphasizes that about 46% of the areas have potential as agriculture land. If this land comes under agriculture, then it will help to improve economic conditions of the farmers in the study region. Hence, further research has a scope to focus on watershed management in the study region.

Error matrix has been used for accuracy assessment. The highly suitable land and unsuitable land are estimated about 97 and 94% accuracy for producers and about 92 and 95% for users, respectively. Marginally and moderately suitable land shows lesser accuracy compared to highly and not suitable land (Table 7). The overall accuracy of the classified final map is estimated at about 90.93% with variation in producer's and user's accuracy. The present study makes it clear that satellite-based maps, i.e., LULC and soil depth, are more reliable for agricultural suitability analysis.

Conclusions

The GIS-based multi-criterion evaluation technique, i.e., AHP, pairwise comparison matrix, weighted overlay analysis, correlation analysis, etc., is better for detecting suitable land in hilly zone. The study was conducted using eight criteria related to physiographic properties on agriculture, i.e., slope, soil depth, LULC, MWHC, soil texture, soil erosion, elevation, and pH. Out of them, slope, LULC, and soil depth are observed to have high influence on agriculture. pH in the region was found to be highly and moderately suitable for chemical environment of agriculture. Weights of criteria were calculated using PCM and scores were assigned based on expert opinion, literature survey, and correlation analysis. The final agricultural LS map shows significant relationships between physical environment like slope, soil depth, MWHC, etc. Correlation analysis shows that agriculture production is negatively associated to slope and positively associated with soil depth. It means that the topographical factors, i.e., slope, have maximum influence on agriculture. About 19% of reviewed land is highly suitable, 16% is moderately suitable, 34% is marginally suitable, and 31% is not suitable for agriculture. Moderately and marginally suitable land required the irrigation facility for efficient agriculture. This study emphasized that about 46% of the areas have potential as agriculture land. If this area came under agriculture, then it will help to fully improve the economic condition of the farmers.

Acknowledgements I would like to thank the Principal and Management of K.V.N. Naik Shikshan Prasarak Sanstha, Nashik for encouraging me to complete this research work. The author wishes to thank the anonymous reviewers for their thorough reviews. I would like to thank to Dr. Vijay Bhagat, Dr. Bharat Gadakh, Prof. Arjun Doke, and Dr. Santosh Bhailume for their genuine help during this research work and also thankful to the Department of Geography, K.T.H.M. College Nashik (Maharashtra, India) using Geo-informatics lab for data processing. Further, Prof. Dilip Kute and Dr. Sanjay Sanap are also thanked for language correction.

References

- Akbulak C (2010) Analitik Hiyerarsi surecive cografi bilgi sistemleriile yukarı kara menderes havzasinin arazi kullanimi uygunluk analizi. *Uluslararası İnsan Bilimleri Dergisi* 7(2):557–576
- Akinci H, Ozalp AY, Turgut B (2013) Agriculture land use suitability analysis using GIS and AHP technique. *Comput Electron Agric* 97:71–82
- Bandyopadhyay S, Jaiswal RK, Hegde VS, Jayaraman V (2009) Assessment of land suitability potentials for agriculture using a remote sensing and GIS based approach. *Int J Remote Sens* 30(4): 879–895
- Barah BC (2010) Hill agriculture: problems and prospects for mountain agriculture. *Indian J Agric Econ* 65(3):584–601
- Bhagat VS (2012) Use of remote sensing techniques for robust digital change detection of land: a review. *Recent Patents on Space Technology* 2:123–144
- Bhagat VS (2014) Agriculture water balance of micro-watershed using GIS techniques. *J Earth Sci Res* 2(1):1–12
- Bojorquez-Tapia LA, Diaz-Mondragon S, Ezcurra E (2001) GIS-based approach for participatory decision making and land suitability assessment. *Int J Geogr Inf Sci* 15(2):129–151
- Ceballos-Silva A, López-Blanco J (2003a) Evaluating biophysical variables to identify suitable areas for oat in Central Mexico: a multi-criteria and GIS approach. *Agric Ecosyst Environ* 95:371–377
- Ceballos-Silva A, López-Blanco J (2003b) Delineation of suitable areas for crops using a multi-criteria evaluation approach and land use/cover mapping: a case study in Central Mexico. *Agric Syst* 77:117–136
- Cengiz T, Akbulak C (2009) Application of analytical hierarchy process and geographic information systems in land-use suitability evaluation: a case study of Dumrek village. *Int J Sust Dev World* 16(4): 286–294
- Census of India (2011) District census handbook, Nashik. Series - 28, Part XII-B
- D'haeze D, Deckers J, Raes D, Phong TA, Loi HV (2005) Environmental and socio-economic impacts of institutional reforms on the agricultural sector of Vietnam land suitability assessment for Robusta coffee in the Dak Gan region. *Agric Ecosyst Environ* 10:59–76
- Datye VS, Gupte SC (1984) Association between agricultural land use and physico-socio-economic phenomena: a multivariate approach. *Transaction Institute of Indian Geographer* 6(2):61–72
- Demir M, Yıldız ND, Bulut Y, Yılmaz S, Özer S (2011) Alan Kullanım Planlamasında Potansiyel Tarım Alanlarının Ölçütlerinin Coğrafi Bilgi Sistemleri (CBS) Yöntemi ile Belirlenmesi. *İğdır Üniversitesi Fen Bilimleri Enstitüsü Dergisi* 1(3):77–86
- Deshmukh KK, Aher SP (2016) Assessment of the impact of municipal solid waste on groundwater quality near the Sangamner City using GIS approach. *Water Resour Manag* 30:2425–2443. <https://doi.org/10.1007/s11269-016-1299-5>
- Duc T (2006) Using GIS and AHP technique for land-use suitability analysis, International symposium on geo-informatics for spatial infrastructure development in earth and allied sciences, organized by Japan-Vietnam geo-informatics consortium institute for environment and resources, Vietnam. Polytechnic University of Hochiminh City, Vietnam

- Dumanski J (1997) Criteria and indicators for land quality and sustainable land management. *ITC J* 3(4):216–222
- Elsheikh R, Abdul RB, Shariff M, Amiri F, Ahmad NB, Balasundram S, Soom M (2013) Agriculture land suitability evaluator (ALSE): a decision and planning support tool for tropical and sub-tropical crops. *Comput Electron Agric* 93:98–110
- FAO (2006) Fertilizer and plant nutrition.. Food and Agriculture Organization of the United Nations, Rome, Italy. bulletin 16
- FAO, WFP and IFAD (2012) The state of food insecurity in the world 2012. Economic growth is necessary but not sufficient to accelerate reduction of hunger and malnutrition. Rome, Italy
- Feizizadeh B, Blaschke T (2012) Land suitability analysis for Tabriz County, Iran: a multi-criteria evaluation approach using GIS. *J Environ Plan Manag* 1:1–23
- Foshtomi MD, Norouzi M, Rezaei M, Akef M, Akbarzadeh A (2011) Qualitative and economic land suitability evaluation for tea in sloping area of Guilan, Iran. *J Biol Environ Sci* 5(15):135–146
- Garcia JL, Alvarado A, Blanco J, Jimenez E, Maldonado AA, Cortés G (2014) Multi-attribute evaluation and selection of sites for agricultural product warehouses based on an analytic hierarchy process. *Comput Electron Agric* 100:60–69
- Iqbal M, Khan I (2014) Spatiotemporal land use land cover change analysis and erosion risk mapping of Azad Jammu and Kashmir, Pakistan. *Egypt J Remote Sens Space Sci* 17:209–229
- Jafari S, Zaredar N (2010) Land suitability analysis using multi attribute decision making approach. *Int J Environ Sci Dev* 1(5):441–445
- Jankowski P (1995) Integrating geographical information system and multiple criteria decision making methods. *Int J Geogr Inf Syst* 9(3):251–273
- Jin XM, Zhang YK, Schaepman ME, Clevers JGPW, Su Z (2008) Impact of elevation and aspect on the spatial distribution of vegetation in the Qilian mountain area with remote sensing data. *Int Arch Photogramm Remote Sens Spat Inf Sci* 37(B7):1385–1390
- Joerin F, Theriault M, Musy A (2001) Using GIS and outranking multi-criteria analysis for land-use suitability assessment. *Int J Geogr Inf Sci* 15(2):153–174
- Kalogirou S (2002) Expert systems and GIS: an application of land suitability evaluation. *Comput Environ Urban Syst* 26:89–112
- Kauko T (2006) What makes a location attractive for the housing consumer? Preliminary findings from metropolitan Helsinki and Randstad Holland using the analytical hierarchy process. *J Housing Built Environ* 21(2):159–176
- Krishnamurthy J (1997) The evaluation of digitally enhanced Indian remote sensing satellite (IRS) data for lithological and structural mapping. *Int J Remote Sens* 18(16):3409–3437
- Lunetta RS, Elvidge CD (1998) Remote sensing change detection. *Ann Arbor press, Michigan*
- Malczewski J (1999) GIS and multi-criteria decision analysis. John Wiley and Sons Inc., New York
- Malczewski J (2004) GIS-based land suitability: a critical overview. *Prog Plan* 62:3–65
- Malczewski J (2006) GIS-based multi-criteria decision analysis: a survey of the literature. *Int J Geogr Inf Sci* 20(7):703–726
- Mendas A, Delali A (2012) Integration of multi-criteria decision analysis in GIS to develop land suitability for agriculture: application to durum wheat cultivation in the region of Mleta in Algeria. *Comput Electron Agric* 83:117–126
- Miller W, Collins W, Steiner FR, Cook E (1998) An approach for greenway suitability analysis landscape and urban planning. *Int J Geogr Inf Sci* 42(2–4):91–105
- Mojid MA, Mustafa SMT, Wyseure GCL (2009) Growth, yield and water use efficiency of wheat in silt loam-amended loamy sand. *J Bangladesh Agric Univ* 7(2):403–410
- Mokarram M, Aminzadeh F (2010) GIS-based multi-criteria land suitability evaluation using ordered weight averaging with fuzzy quantifier: a case study in Shavur plain Iran. *Int Arch Photogramm Remote Sens Spat Inf Sci* 38(2):508–512
- Mustafa AA, Singh M, Sahoo RN, Ahmed N, Khanna M, Sarangi A (2011) Land suitability analysis for different crops: a multi-criteria decision making approach using remote sensing and GIS. *Researcher* 3(12):61–84
- Olayeye AO, Akinbols GE, Marake VM, Molete SF, Mapheshoane B (2008) Soil in suitability evaluation for irrigated lowland rice culture in South-Western Nigeria: management implications for sustainability. *Commun Soil Sci Plant Anal* 39:2920–2938
- Perveen F, Ryota N, Imtiaz U, Hossain KMD (2007) Crop land suitability analysis using a MCE and GIS approach. 5th international symposium on digital earth. University of California, Berkeley, pp 1–8
- Prakash TN (2003) Land suitability analysis for agricultural crops: a fuzzy multi-criteria decision making approach. M.sc thesis. The International Institute for geo-information Science and Earth Observation (ITC), Enschede, The Netherlands, pp 6–13
- Rabia AH (2012) Mapping soil erosion risk using rusle, GIS and remote sensing techniques. In: The 4th international congress of ECSSS, EUROSOIL. Bari, Italy
- Rabia AH, Terribile F (2013) Introducing a new parametric concept for land suitability assessment. *Int J Environ Sci Dev* 4(1):15–19
- Ravi S, Breshears DD, Huxman TE, D'Odorico P (2010) Land degradation in drylands: interactions among hydrologic-aeolian erosion and vegetation dynamics. *Geomorphology* 116:236–245
- Saaty TL (1980) The analytic hierarchy process: planning, priority setting, resource allocation. McGraw Hill International, New York
- Saaty TL (1997) A scaling method for priorities in hierarchical structures. *J Math Psychol* 15:234–281
- Sarkar A, Ghosh A, Banik P (2014) Multi-criteria land evaluation for suitability analysis of wheat: a case study of a watershed in eastern plateau region, India. *Geo-spatial Information Science* 17(2):119–128
- Shalaby A, Ouma YO, Tateishi R (2006) Land suitability assessment for perennial crops using remote sensing and geographic information systems: a case study in North-Western Egypt. *Arch Agron Soil Sci* 52(3):243–261
- Soltani SR, Mahiny AS, Monavari SM, Alesheikh AA (2012) A soft approach to conflict resolution in multi-criteria evaluation of urban land use suitability. *World Appl Sci J* 19(7):1066–1077
- Srdjevic Z, Kolarov V, Srdjevic B (2007) Finding the best location for pumping stations in the Galovica drainage area of Serbia: the AHP approach for sustainable development. *Bus Strateg Environ* 16(7):502–511
- Steiner F, McSherry L, Cohen J (2000) Land suitability analysis for the upper Gila river watershed. *Landsc Urban Plan* 50:199–214
- Thompson LM, Troeh FR (1973) Soils and soil fertility. McGraw-Hill Publications in the Agriculture Sciences
- Wang F (1994) The use of artificial neural networks in a geographical information system for agricultural land-suitability assessment. *Environ Plan A* 26(2):265–284
- Wang F, Hall GB, Subaryono (1990) Fuzzy information representation and processing in conventional GIS software: data base design and applications. *Int J Geogr Inf Syst* 4(3):261–283
- WMO (2005) Climate and land degradation. World Meteorological Organization (WMO) Publication No. 989. Available online at <http://www.wmo.int>. Accessed 14 March 2014
- Yalew SG, Griensven A, Mul ML, Zaag P (2016a) Land suitability analysis for agriculture in the Abbay basin using remote sensing, GIS and AHP techniques. *Model Earth Syst Environ* 101:1–14. <https://doi.org/10.1007/s40808-016-0167-x>
- Yalew SG, Griensven A, Zaag P (2016b) AgriSuit: a web-based GIS-MCDA framework for agricultural land suitability assessment. *Comput Electron Agric* 128:1–8
- Zolekar RB, Bhagat VS (2014) Use of IRS P6 LISS-IV data for land suitability analysis for cashew plantation in hilly zone. *Asian Journal of Geoinformatics* 14(3):23–35
- Zolekar RB, Bhagat VS (2015) Multi-criteria land suitability analysis for agriculture in hilly zone: remote sensing and GIS approach. *Comput Electron Agric* 118-C:300–321