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ORIGINAL ARTICLE

Site suitability analysis for agricultural land use of Darjeeling district using AHP and GIS techniques

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Abstract Darjeeling district covered with 60.89 % of its land under Himalayan dense forest producing exquisite biodiversity and variations in climate with a diversified fauna and flora. Therefore, designs great scope for agricultural development in the rural area of the Himalayan foothills to boost rural economies. However, agriculture not mostly developed in this district due to different physical threats (such as very high slope and elevation, dense vegetation cover, fewer irrigation facilities, dry soil, etc.), socio-economic problems and lack of adequate transportation. Land suitability analysis can help to establish the strategies for the development of agricultural productivity. AHP with the integration of GIS-based multi-criterion decision making an approach using DEM and Landsat 8 satellite data was utilized to evaluate land suitability for agriculture production in hilly areas. Various 'expert opinions' was used to determine the results of selected parameters whereas pairwise comparison matrix used to established the weights. About, 5.31 % area is classified in the class highly suitable, 29.82 % in moderately suitable, 24.27 % in marginally suitable, and 40.60 % in unsuitable for agriculture. The techniques, methodology and results of the study can be effective to assess the suitable land for agriculture in hilly regions.

Keywords Analytic hierarchy process · Agricultural land use suitability · Model builder toolbox · Darjeeling · Multi-criterion decision analysis · Moisture index

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Introduction

Darjeeling district is famous for its fascinating hill station (Queen of the Hills) and tea garden. The economy of the region mainly depends on the tea industry and tourism. Besides tea, the most extensively cultivated crops include millets, maize, potato, ginger and cardamom. Therefore, pleasant climatic condition and rich biodiversity may lead to the development of agricultural activities, as well as rural tourism. The development of agricultural activities and management of rural tourism are necessary for the protection and conservation of natural resources with economic enhancement of the local villagers. Darjeeling district has been challenges of various natural disasters in recent times and unemployment that may promote the people's migration from hilly areas to the plains. Moreover, environmental problems due to tourism and land cover disturbance are major problems in hilly regions (Boori et al. 2014). Agricultural development and rural tourism can play a necessary role to make villagers self-sustainable as well as socio-economic development. Food safety and degradation of environmental quality concerns due to the unprecedented use of fertilizers, pesticides promoted the agricultural planning (i.e., organic farming) in recent times (Lapple and Cullinan 2012).

Land suitability analysis (LSA) is a method to encounter inherent and potential capabilities (Bandyopadhyay et al. 2009), and suitability for different objectives (FAO 1976). Land assessment measures the degree of land usefulness for potential land use by land requirement and qualities (FAO 1976; Hopkins 1977; Malczewski 2004). Multi-criterion evaluation (MCE) method is mostly applied for land suitability analysis. Multi-criterion evaluation of land suitability involves different criteria like geological and biophysical elements (i.e., geology, soil characteristics,

Table 1 Techniques, parameters, fields and data used for land suitability mapping

Suitability field	Techniques	Parameters	Data	References
Land use	AHP	Land-use capability class, soil depth, erosion hazard, elevation, slope, distance from water source, limiting soil factors and distance to road	Thematic maps	Cengiz and Akbulak (2009)
Agriculture	AHP	LULC, organic matter, soil depth, soil type and slope	Satellite data: IRS-1D LISS-III and thematic maps	Bandyopadhyay et al. (2009)
Rangeland management	AHP	Elevation, slope, climate, LULC, soil depth, soil hydrology, soil texture, soil structure, erosion, vegetation density and types, temperature, rainfall, distance from surface water and distance from population centers	Thematic maps	Jafari and Zaredar (2010)
Public parks	AHP and WLC	Available land, population density and land value	Thematic maps	Chandio et al. (2011)
Agriculture	AHP	Slope, elevation, aspect, soil PH, soil fertility, precipitation, temperature and groundwater	Thematic maps, SPOT 5	Feizizadeh and Blaschke (2012)
Agriculture	AHP	Land use, soil depth, Soil groups, erosion, elevation, slope, aspect and soil parameters	Field base data and thematic maps	Akinci et al. (2013)
Agricultural product warehouses	AHP	Accessibility, security, Needs of the agricultural product warehouse, security, accessibility, acceptance and costs	Thematic maps	Garcia et al. (2014)

relief, atmospheric conditions, vegetation etc.), as well as economic and socio-cultural conditions in decision making process (Joerin et al. 2001) to solving different land problems with multiple alternatives (Wang et al. 1990; Jankowski 1995; Yu et al. 2011). Geographical information system (GIS) is a useful technique to investigates the multiple geospatial data with precision and higher flexibility in land suitability analysis (Mokarram and Aminzadeh 2010; Mendas and Delali 2012). Therefore, multi-criteria decision making (MCDM) process has been integrated with geospatial techniques in various studies for the potential land use decision-making process to solve complex problems of land management with best alternatives (Cengiz and Akbulak 2009; Malczewski 2006; Mendas and Delali 2012). This techniques extensively used for land suitability analysis to identify the potential lands for watershed management (Steiner et al. 2000), plantation (Zolekar and Bhagat 2014), agriculture (Shalaby et al. 2006; Bandyopadhyay et al. 2009; Jafari and Zaredar 2010; Cengiz and Akbulak 2009; Chandio et al. 2011; Feizizadeh and Blaschke 2012; Akinci et al. 2013; Garcia et al. 2014), etc.

Development of agricultural land use has a great potentiality in Darjeeling district due to its favorable environmental and climatic conditions. To acquire suitable land for maximum production, local geological and environmental conditions are essential factors. Identification of suitable sites for agricultural land use requires consideration of geophysical limitations, various topological and climatic environment (Kamkar et al. 2014; Bandyopadhyay et al. 2009; Feizizadeh and Blaschke 2012). Therefore, recent and accurate land use/land cover (LULC), and other environmental, geographical data should be considered for the determination of suitable agricultural land use (Wang 1994; Deep and Saklani 2014; Duc 2006). The parameters like LULC, slope, elevation, soil depth, soil moisture, soil texture, soil erosion, and soil nutrients are frequently used for assessment of land characteristics and suitability's for agricultural production (Table 1). Site suitability assessment of agricultural development includes the assessment of a large amount and variety of physiographic data, climatic characteristics (rainfall and temperature), internal soil condition (depth, moisture, texture, salinity and natural fertility), and external soil conditions (slope, accessibility and flooding) (Wang 1994). Geospatial techniques can be utilised for the identification of the suitable sites for the agricultural lands on different criteria like geology, topography, soil characteristics, drainage, and transport pattern of the study area. However, this technique can also use to prioritize and identify the potential sites for the agricultural land use pattern.

Further, Analytic hierarchy process (AHP) is extensively utilized for multi-criterion decision making of land suitability for the various field. It determines the weight of importance for different land use based on pairwise comparisons of various parameters according to their relative significance (Miller et al. 1998). Analytic hierarchy process was firstly developed by Saaty (1980), establish a hierarchical model for solving complex problems of land management with best alternatives (Malczewski 2006; Cengiz and Akbulak 2009; Roig-Tierno et al. 2013). As a multi-criterion decision-making method, the analytic hierarchy process has been used widely for solving an extensive variety of problems based on complex parameters across various levels where the interaction among parameters is common characteristics (Tiwari et al. 1999).

Weighted overlay method (WOM) along with the analytic hierarchy process provides a very assuring outcome for the site suitability assessment of agricultural land use. The method can be useful to the multi-level hierarchical structure of various constraints and criteria (Triantaphyllou and Mann 1995). It has steps to analyze the relative influence of weights on each parameter, before obtaining the final score (Boroushaki and Malczewski 2008; Bunruamkaew and Murayam 2011). Analytical hierarchy

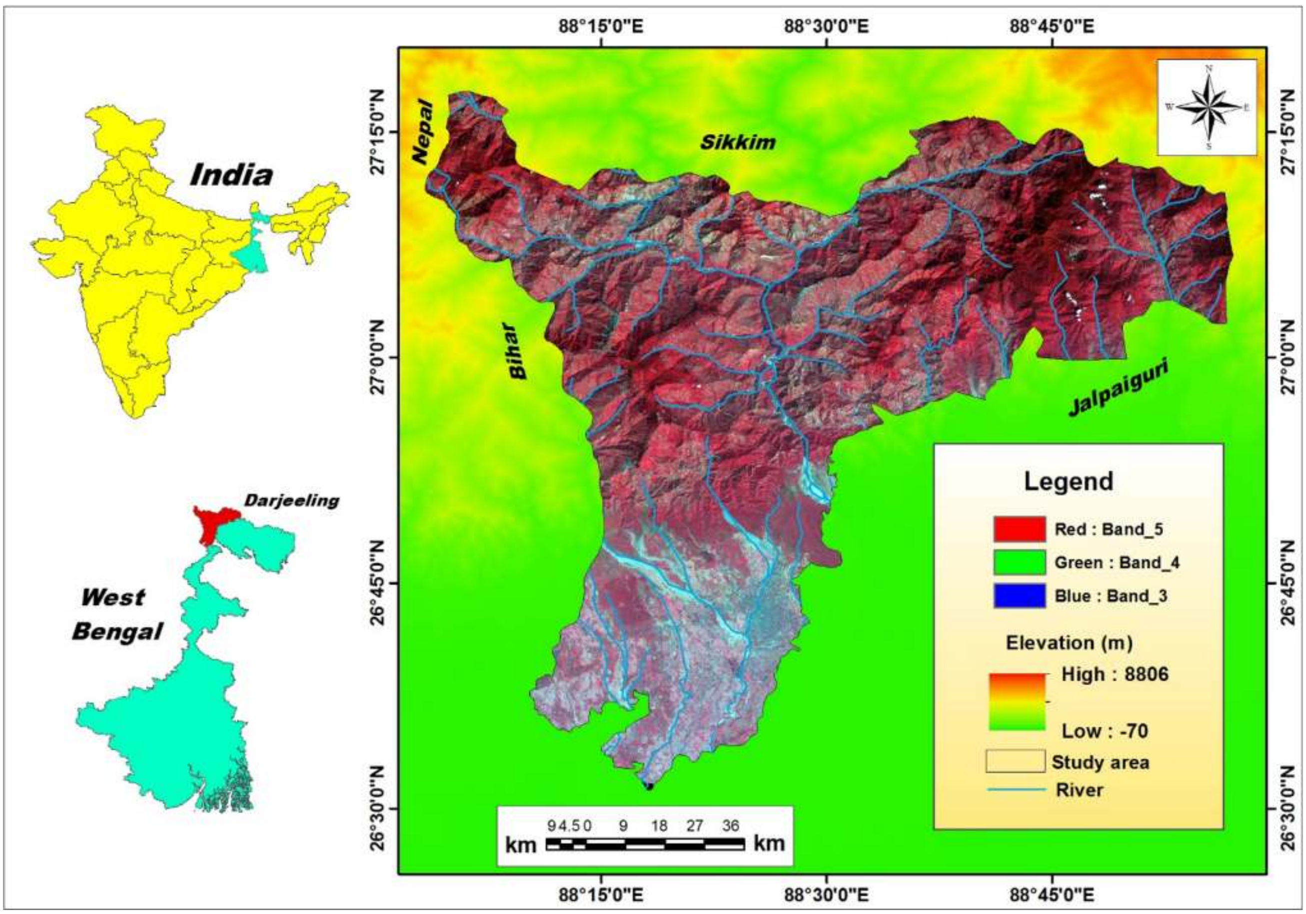

Fig. 1 Location map of the study area

Table 2 Parameter used in the habitat suitability indices and their types, details and sources

Parameters	Data type	Data sources	Details about data	Period
Slope, elevation, aspect	Spatial	SRTM DEM and Arc-GIS toolbox	3-ARC (90 m)	2000
LULC	Spatial	OLI images	USGS satellite images	2015
Soil moisture	Spatial	IR and Green band of OLI images	USGS satellite images	2015
Drainage and transport network	Spatial	Digitized feature	Open street map and toposheets (SOI)	2015
Soil characteristics, geology	Spatial	Digitized feature	NATMO and GSI	2015

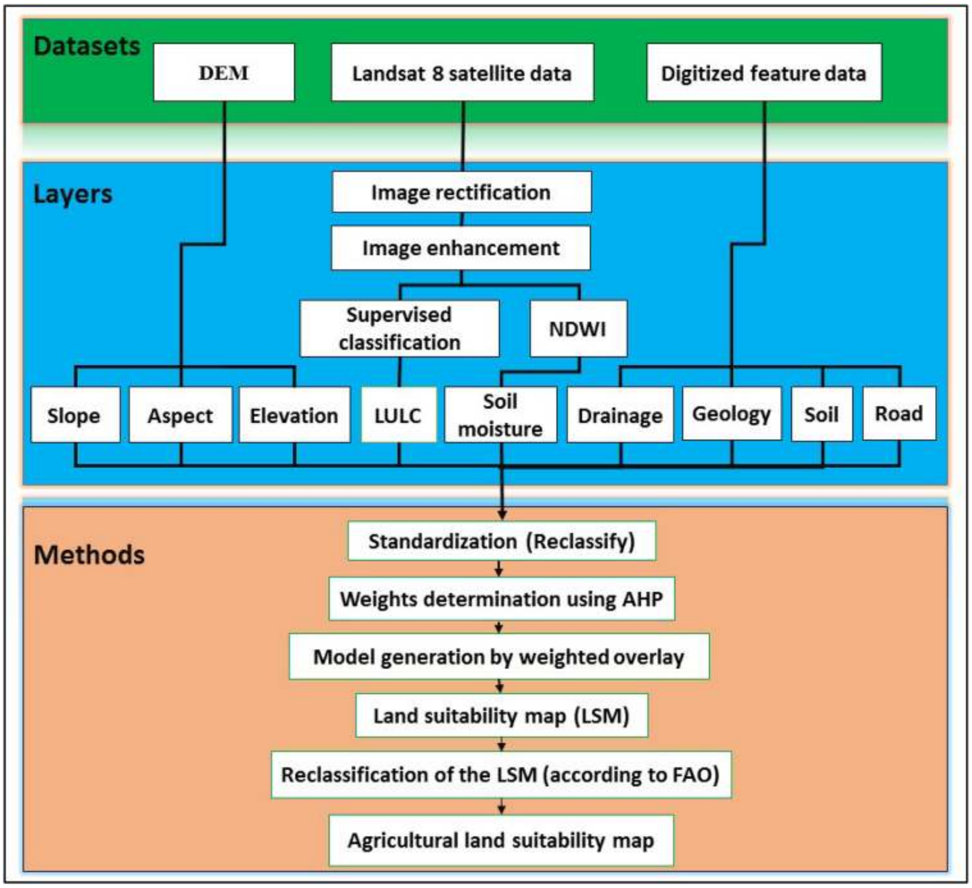

Fig. 2 Procedure followed in generating suitability map of agricultural production

process is one of the auspicious method utilized for agricultural land suitability assessment based on individual parameters through quantitative assessment (Chen et al. 2010a, b; Akinci et al. 2013; Khahro et al. 2014). Pairwise comparison is also used to calculate the overall score of individual elements or criteria. Integration of GIS and analytical hierarchy process helps to decision support system by the generation of suitability maps (Khahro et al. 2014).

However, land use suitability and its mapping are one of the most effective utilizations of the geospatial techniques (Javadian et al. 2011). GIS techniques are also used to construct various criteria maps which are applied in analytical hierarchy process to formulate the site suitability model for agricultural development (Xu et al. 2012). The development of agriculture will not only improve the rural economy but also promote the diversification of poor farmers and rural tourism that can prevent the migration activity of poor people from hilly areas to the plain lands (Boori et al. 2014). Moreover, the very small land is available for agricultural development in the study area because of high variation in elevation and abundance of natural resources. The identification of suitable lands which is having the highest productivity as well as highest net profit on lesser input is expected and prioritized in the hilly areas. So, the suitability analysis of agricultural land is an appropriate and strong method for the hilly areas. The main objectives of the study are to identify the suitable lands for the agricultural development using GIS and analytic hierarchy process in the study area.

Study area

The study was carried out in the Darjeeling district, the northernmost part of the West Bengal (WB) in the foothills of the Eastern Himalayas, India. The study area is situated between the latitude 26°27′ to 27°13′N and longitude 87°59′N–88°53′E, covering an area of 3149 km^2 (Fig. 1). According to the census of 2011, the population of the district, which consists of 13 town and 139 villages, is 18,46,823. While 7,27,963 people live in urban areas, 11,18,860 live in the villages. The population density of the district is 413 person/km^2 (District Census Handbook, Darjiling 2011).

The terrain of the study area is both plain and hilly. The elevation of the district varies from 15 and 3209 m, and the elevation of mean sea level is approximately 750 m in the district center. The hill area is formed by recent rock

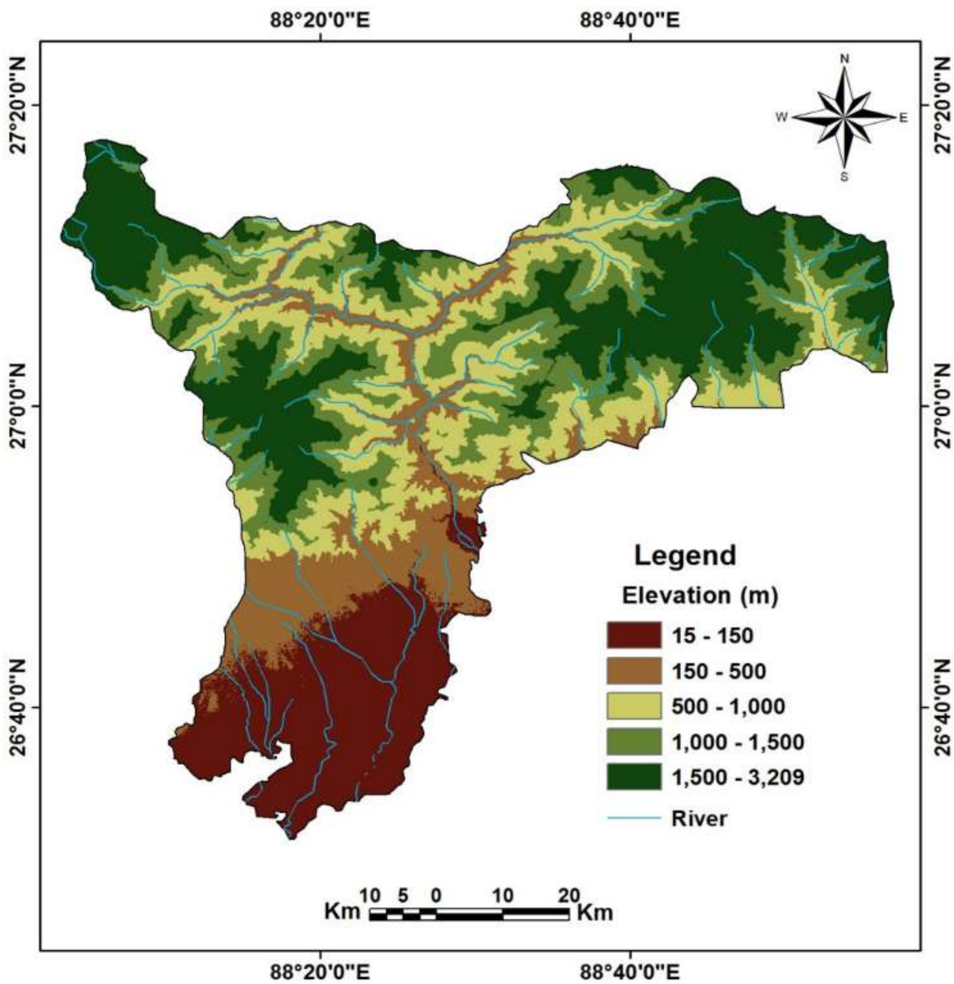

Fig. 3 Elevation map of the study area

structure that has a direct potentiality to landslides by heavy monsoon precipitation. The soil of the Darjeeling hill regions is extremely varied, depending on geo lithology, the degree of slope, elevation, and vegetative cover.

The temperature of the region ranges from 14 to 24 °C in summer, and between 5 and 8 °C in winters (Darjeeling Climatological Table 1901–2000 2015). The hilly areas get heavy rainfall in the monsoon season. Rivulets and streams belonging to the Mahananda, Tista, Mechi, Balason, Jaldhaka, Rammam and Rangit river system flow in the northern portion of the region. The district is also important for the tourism and pilgrimage sites like Tiger Hill, Rock Garden, Mahakal Temple, Dhirdham Temple, Batasia Loop, Ghoom Monastery and Happy Vally Tea Garden, etc.

The economy of the Darjeeling hill region depends on horticulture, tea production, agriculture, tourism, and forestry. Recently, the maximum portion of forests are found at 2000 m elevations and above. The located area between 1000 and 2000 m elevations is cleared either for agricultural activities or tea plantation. The deep soils of Himalayan foothill areas have the potentiality to plantations and agriculture.

Materials and methods

In the present study multi-criterion, site suitability modeling was developed to establish appropriate and potential locations for agricultural development based on a group of constraints and criteria. Depending on their significance and importance in the agriculture seven different constraints and criteria were selected. The identification of different criteria depended on maximum limitation method that influences the product yield of agriculture which includes geology, soil type, elevation, slope, aspects, drainage and distance from roads, etc. (Duc 2006; Akinci et al. 2013). Moreover, weights for the each selected criterion were estimated using analytical hierarchy process and after that weighted overlay method was adopted to establish the suitability map. Table 2 represents the data used, types, and sources for the agriculture site suitability

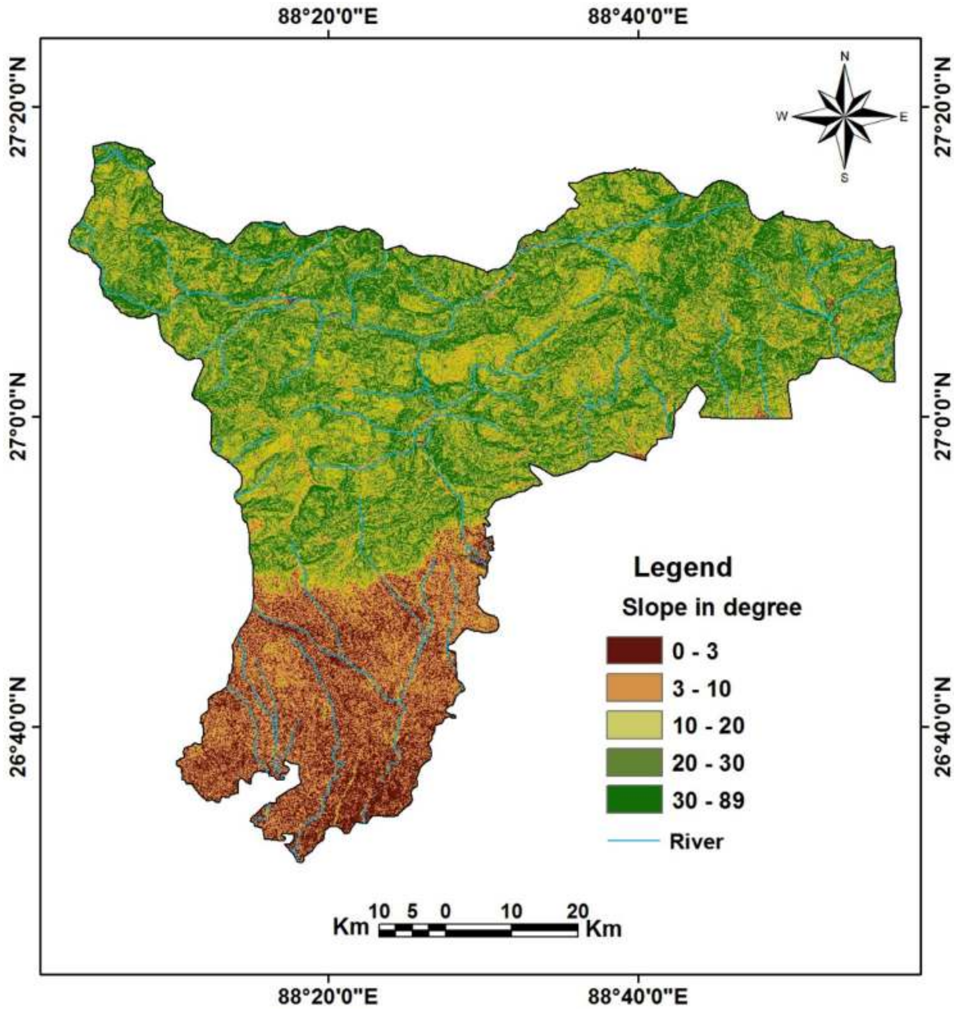

Fig. 4 Slope of the study area

analysis. The methodological flow diagram of the present study is shown in Fig. 2.

Generation of criterion maps using geospatial techniques

Elevation (Fig. 3), slope (Fig. 4), and aspect (Fig. 5) map were generated using Shuttle Radar Topography Mission (SRTM) near-global Digital Elevation Models (DEMs) data of 90 m resolution obtained from United States Geological Survey (USGS). Geology (Fig. 6) and soil (Fig. 7) maps were derived using National Atlas and Thematic Mapping Organisation (NATMO) and Geological Survey of India (GSI) map. Drainage (Fig. 8) and road system (Fig. 9) maps were derived using an open street map and toposheets maps of Survey of India (SOI). Land use/land cover (LULC) map (Fig. 10) and Soil moisture map (Fig. 11) were prepared using Landsat 8 satellite images of 15 m spatial resolution. The moisture map was calculated by Normalised Difference Water Index (NDWI) which is measured using Infra-Red (IR) and Green (G) bands (Eq. 1) of Landsat 8 satellite images.

$$NDWI = \frac{IR - G}{IR + G} \quad (1)$$

Standardization of selected criteria maps

All of the selected criteria are in different units so to execute Weighted Overlay Method they require to be convert in same units and hence required to be standardized value. Standardization techniques convert the measurement to uniform units, and the resulted score lose their dimension along with their measurement unit of all criteria (Effat and Hassan 2013).

The vector layer of all criteria maps was converted to raster layer that has been shown in Fig. 12. After that, all raster layers were reclassified and used for the input data to

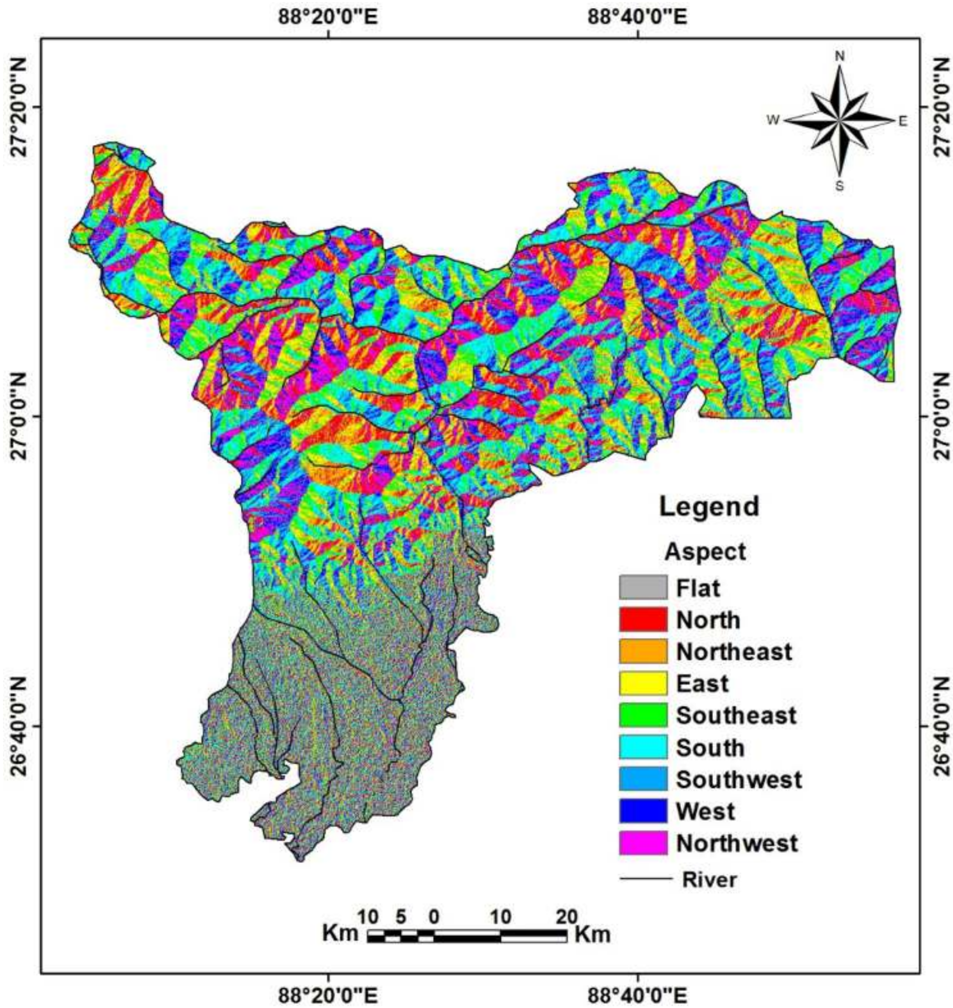

Fig. 5 Aspect map of the Darjeeling district

the weighted overlay method which finally create the suitability map for agriculture. Reclassify method in spatial analyst toolbox of Arc-GIS software, standardizes the value of all selected criteria for the analysis of comparative significance.

Agriculture requires good geology, and soil types with having drainage availability for the irrigation system, roads, and rails are also significant for the easy transportation facility of the raw products of agriculture. While Darjeeling is a mountainous district, elevation, slope and aspect come to the decision-making process (DMP) for identifying suitable land for agricultural development. For suitable site identification, all these parameters were considered during the analysis of potential agriculture zone. All parameters were reclassified in five different category. The sub-criterion were classified into 1–10 different ranking scales where 1 having the least significance and 10 having the highest significance (Table 3).

Calculation of weight for each criterion

Analytic hierarchy process is one of the most significant multicriteria decision-making techniques. The process is applied to a set of criteria or sub-criteria to establish a hierarchical structure by giving the weight of each criterion incomplete decision-making process (Kiker et al. 2005). The weight value analyzes the relative significance of individual criterion and hence to be chosen deliberately. Analytic hierarchy process gives a structural ground for quantifying the strong comparison of design criteria and elements in a pairwise technique and thus decreases the complexity of decision-making process (Miller et al. 1998; Saaty 1977). The process determines the weight values by pairwise comparison technique by relative significance of criterion, taken two at a time (Miller et al. 1998). Using the pairwise comparison matrix, the analytic hierarchy process calculates the weights for the individual criterion by taking the eigenvalue corresponding to the highest eigenvector of

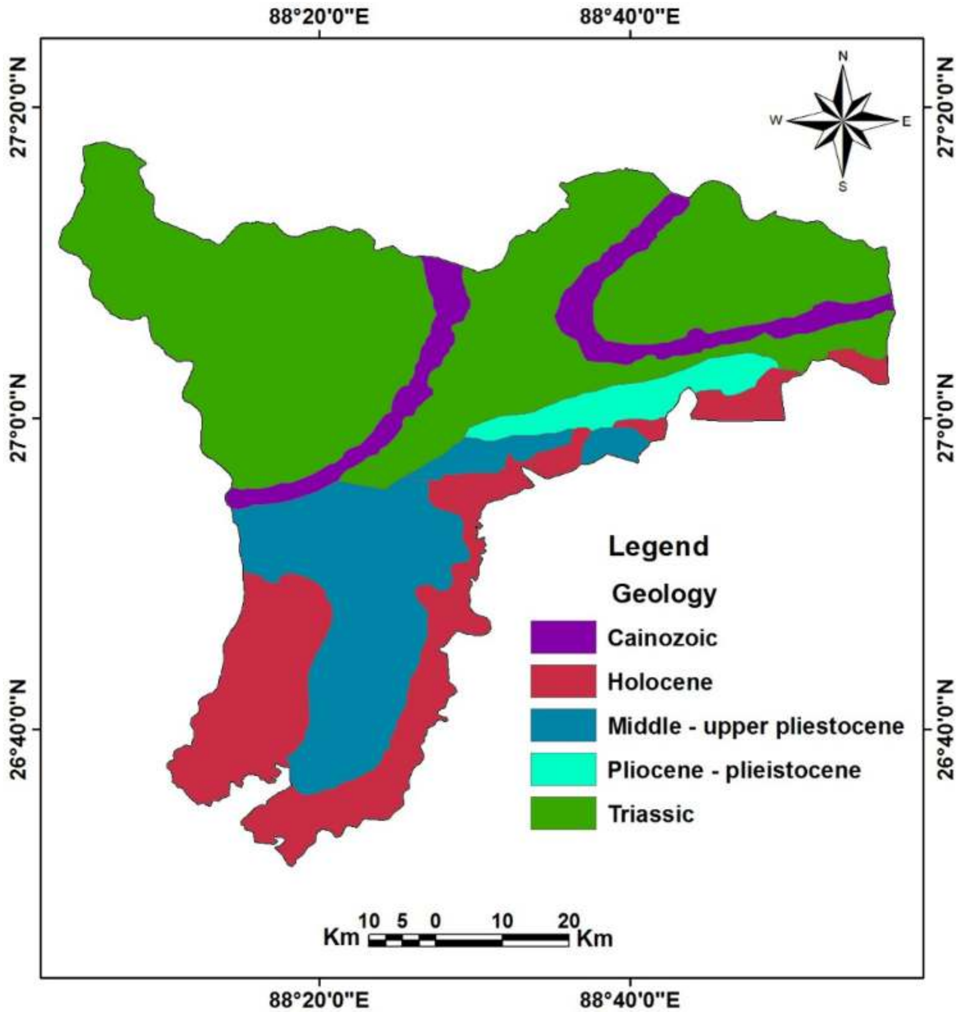

Fig. 6 Geology map of the Darjeeling district

the completed matrix and the normalizing the sum of the factors to unity (Saaty 1980; Malczewski 1999; Feizizadeh et al. 2014).

Using the analytic hierarchy process explained above the pairwise comparison matrix was calculated using the scale of 1–9 where 9 indicates extreme significance and 1 indicates the equal significance of in between criterion of the matrix shown in Table 4 (Saaty 1980; Malczewski 1999; Feizizadeh et al. 2014). The comparison matrix mainly has the criteria of reciprocity which mathematically expressed as, n (n − 1)/2 for n number of components in pairwise comparison matrix (Saaty 1980; Akinci et al. 2013). After the computation of pairwise matrix, relative weights/eigenvectors is calculated using Saaty's method (Saaty 1980) (Tables 5, 6). Moreover, analytic hierarchy process also identifies and calculate the inconsistencies of decision makers which is its one of the significant characteristics (Saaty 1980; Feizizadeh et al. 2014; Garcia et al. 2014). The efficiency criteria of analytic hierarchy process are estimated by consistency relationship (CR) which is measured by Eq. 2.

$$CR = CI/RI \tag{2}$$

Equation 2 represents the CR where CI indicates consistency index and RI indicates the random index.

Consistency relationship facilitates the determination of possible events and measures logical inconsistencies of the decision maker/judgments (Cengiz and Akbulak 2009; Chen et al. 2010a, b). It represents the likelihood where the matrix judgments were formed randomly (Park et al. 2011; Saaty 1977). The CR mainly depends on the Consistency Index and Random Index.

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{3}$$

Equation 3 indicates the Consistency Index (CI) when λmax is the principle or highest eigenvector of the computed matrix and n denotes the order of the matrix.

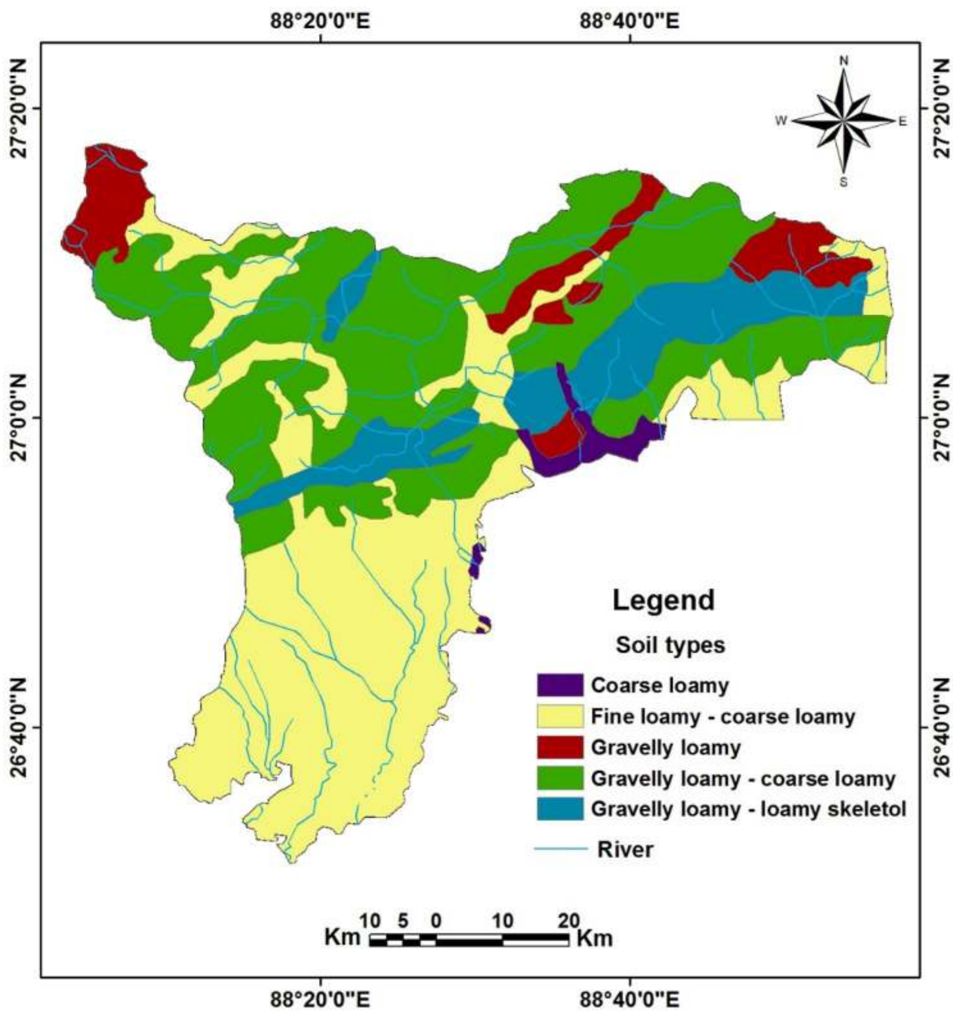

Fig. 7 Soil characteristics of the study area

Random Index (RI) is the mean value of the consistency index depending on the computed matrix order given by Saaty (1977) that has shown in Table 7. If, the value of CR >0.10, then the weight values of the matrix indicates inconsistencies and the method (AHP) may not give a meaningful results (Saaty 1980). In the present study the calculated CR was 0.0669 which is under acceptable limits and the computed weight values are valid. Further, the computed weight values are converted into percentage for weighted overlay analysis (WOA) in GIS, that shown in Table 8.

Site suitability model for agriculture using weighted overlay analysis

The weighted overlay analysis is effective to resolve spatial complexity in suitability analysis and site selection based on general measurement of dissimilar and diverse impacts (Girvan et al. 2003; Kuria et al. 2011). Analytic hierarchy process is applied to determine the influential factors in the hierarchy of selected dissimilar inputs to weighted overlay analysis (Parimala and Lopez 2012). Moreover, all created thematic layer were combined with each other in GIS to applied the weighted overlay techniques (Girvan et al. 2003). Land suitability for agricultural development has been found using weighted overlay techniques based on analytic hierarchy process and multi-criterion decision-making process. Selected raster layers were overlaid by recognizing their cell values to the same scale, giving a weight value to individual criterion and integrating the weight cell values together (Eq. 4). The cell values of each raster layer are also multiplied by their weight value (Mojid et al. 2009; Cengiz and Akbulak 2009) using model builder toolbox of Arc-GIS 10.2.

$$LS = \sum_{i=1}^{n} WiXi \qquad (4)$$

Where, LS indicates the total land suitability score, Wi denotes the weight of the selected land suitability criteria, Xi indicates the assigned sub-criteria score of i land

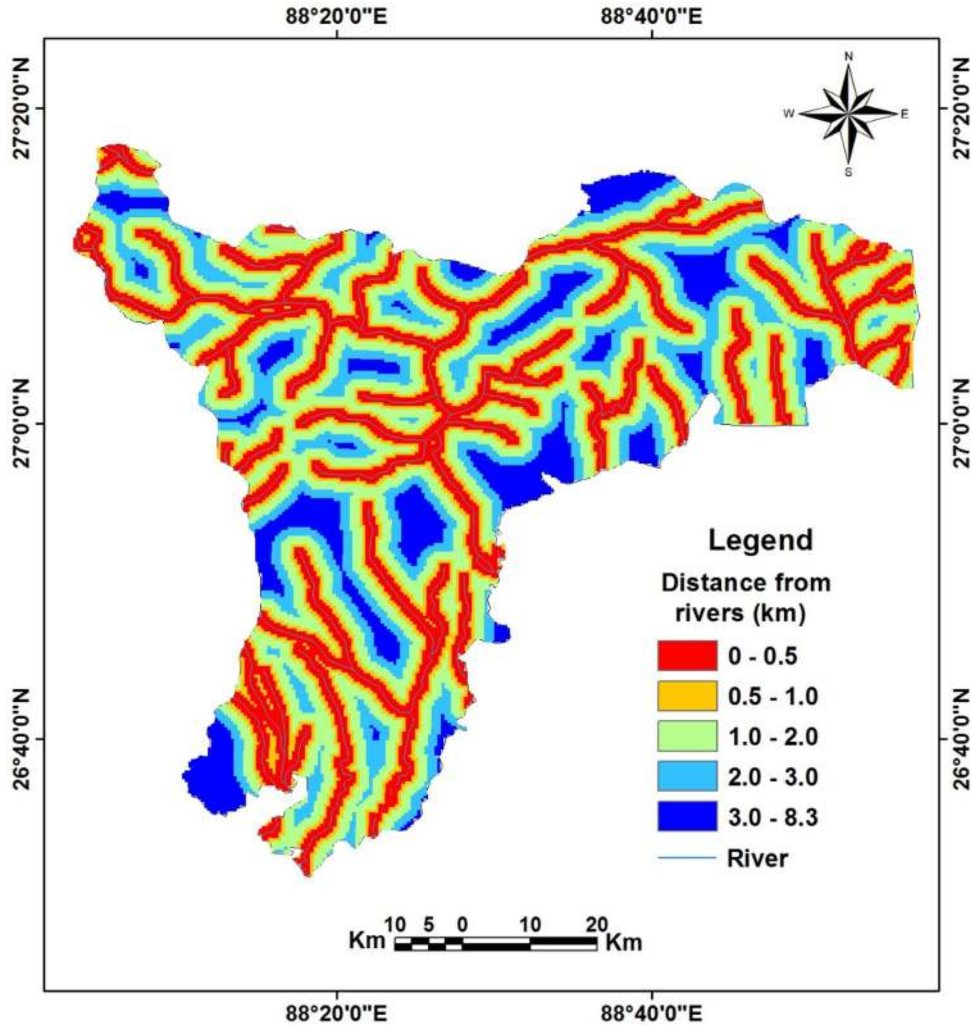

Fig. 8 Distance from rivers of the study area

suitability criteria, and n denotes the total number of land capability criteria (Cengiz and Akbulak 2009).

Results and discussion

The weight values of selected parameters calculated in Analytic Hierarchy Process and designated scores of sub-criterion were used in Weighted Overlay Analysis to generate the land suitability for agriculture in Darjeeling district (Table 8). According to the classification of Food and Agricultural Organization (FAO), land suitability for agriculture classified into five levels i.e., 1. Highly suitable agricultural land, 2. Moderately suitable agricultural land, 3. Marginally suitable agricultural land, 4. Currently not suitable for agriculture, and 5. Permanently not suitable for agricultural production (Table 9).

According to the generated land suitability map for agriculture, it was determined that 5.31 % (16,722.94 ha) of the study area be highly suitable for agricultural production, 29.82 % (93912.99 ha) is moderately suitable, 24.27 % (76,434.21 ha) is marginally suitable land, 38.18 % (120,241.38 ha) is currently not suitable land for agricultural production, and 2.42 % (7621.37 ha) is permanently unsuitable (Fig. 13).

High elevation (15–3209 m), high slope (3°–89°) with higher intensity of gully erosion, lower drainage availability of the study area were efficient factors, resulting in a less area/lower rate of highly suitable agricultural land in the Darjeeling district. Similarly, in a study of agricultural land suitability evaluation for the hilly areas of Ispir, Erzurum (Turkey), similar results were found, as a lower rate/less area of 0.4 % area for highly suitable agriculture was computed (Akinci et al. 2013). The present study

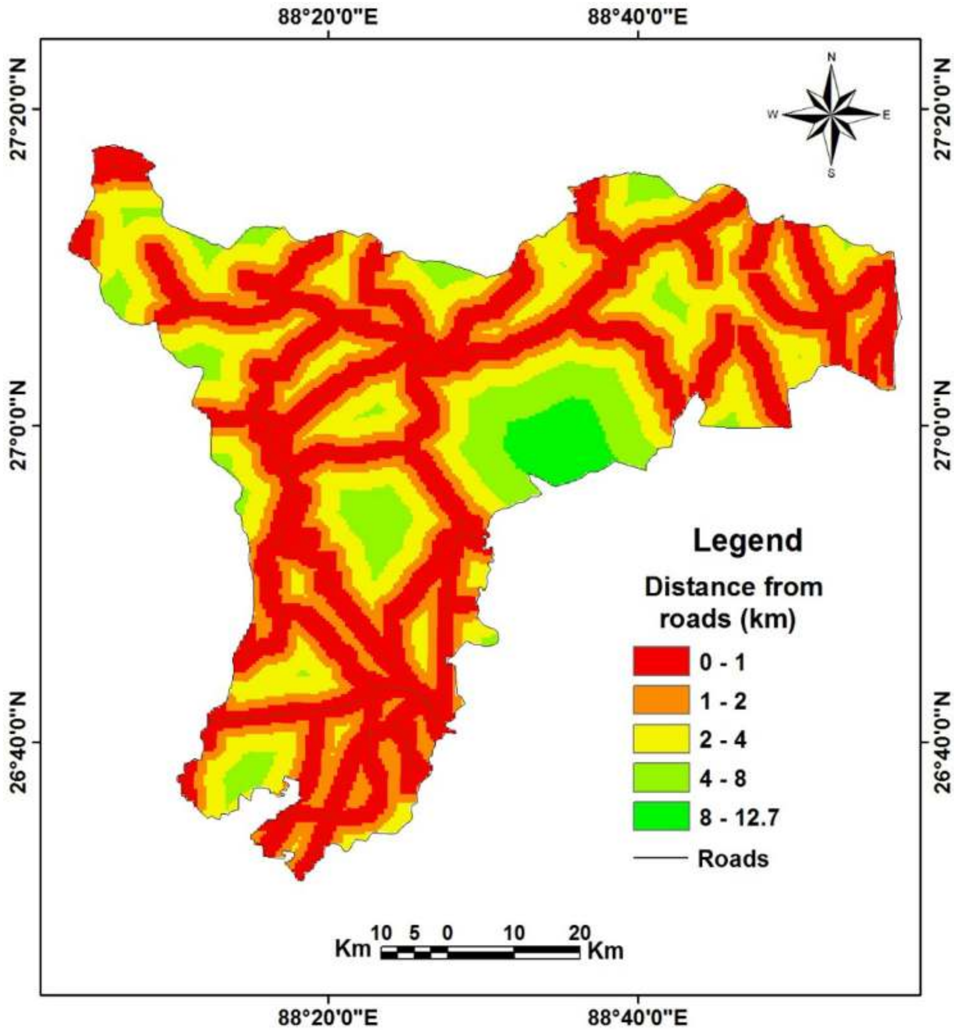

Fig. 9 Distance from roads of the study area

signifies that the large precipitous slope in Darjeeling district not only indicate the common characteristics of agricultural lands but also restrict potential agricultural production in the study region.

Vegetation/forest and tea plantation cover 64.91 % (304,391.45 ha) of the study district (Table 9). While 18.6 % (58,577.52 ha) of the study area that is marginally suitable land for agricultural production coincides with forest land/vegetal cover and tea plantation area, 1.8 % (5668.79 ha) of highly suitable agricultural land and 6.5 % (20,470.64 ha) of moderately suitable agricultural land coincide with forest land and tea plantation area. Because suitable land for agriculture cannot be carried out in dense vegetal cover and tea planted areas, under legal rules and regulations in Darjeeling district, these areas were eliminated from generating suitability map and another new agricultural suitability map was established, as shown in Fig. 14.

With the consideration of the waterbodies (River, reservoir, lakes, ponds, etc.) and barren lands of the Darjeeling district, Mirik reservoir, Senchal Lake and different perennial rivers in the study areas, it was computed that 12,376.85 ha of suitable areas will be inundated/flooded (Table 9). It was established that the highly suitable land for agriculture production will be particularly damaged by this flooded condition. 0.40 % (1259.73 ha) of this highly suitable agricultural land, 3.10 % (9762.92 ha) of moderately suitable land, and 0.38 % (1196.74 ha) of marginally suitable agricultural land will be lost due to inundation by waterbodies and sand deposition of the study area. Figure 15 shows the final agricultural suitability map generated by removing the waterbodies and barren lands of the Darjeeling district.

Therefore, the extent to which the recent agricultural/farming areas correspond to the suitability map of agriculture and how this agricultural land will be affected

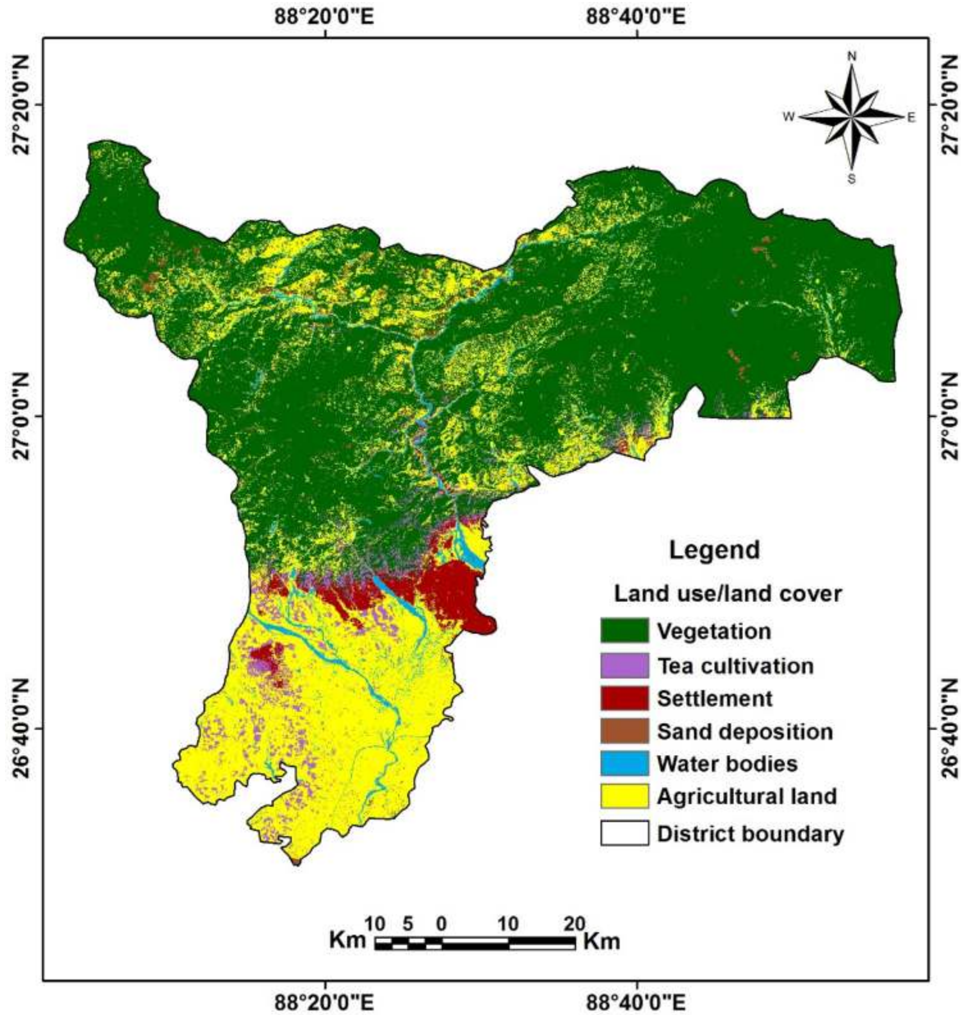

Fig. 10 LULC map of Darjeeling district

by the water bodies and barren lands were determined in the present study. Establishing the land use land cover map of the study shows that only 28.21 % (88,843.95 ha) of the study area is recently used for agriculture. Also, it was determined that 29.82 % (93,912.99 ha) of the highly suitable lands, 5.31 % (16,722.94 ha) of the moderately suitable lands, and 24.27 % (76,434.21 ha) of the marginally suitable lands be currently used for agriculture in the Darjeeling district.

In recent, the construction of large dams and reservoirs appear to be imminent considering that dams and reservoirs help irrigation for hydroelectric power, drinking water, and agricultural production for rapid increasing population growth in the study region. Consequently, construction of large dams and reservoirs cover significant role in the Darjeeling's investment budget that enforced to the different kind of environmental problems of Darjeeling district and its immediate environment (Bhutia 2014). However, it is also common characteristics that large reservoirs and dams can severally modify the river systems (both perennial and non-perennial river) they are built on and their surrounding environment. Also, large dams and reservoirs with entire drainage system can cause economic, social, and cultural losses as they immediate agricultural lands, cultural heritage and settlements (Bhutia 2014).

In the present study, it was established that agricultural activities are carried out in 38.18 % (120,241.38 ha) of the area of this region is currently unsuitable for agriculture production and 2.42 % (7621.38 ha) of the area that is permanently unsuitable for agricultural production. By

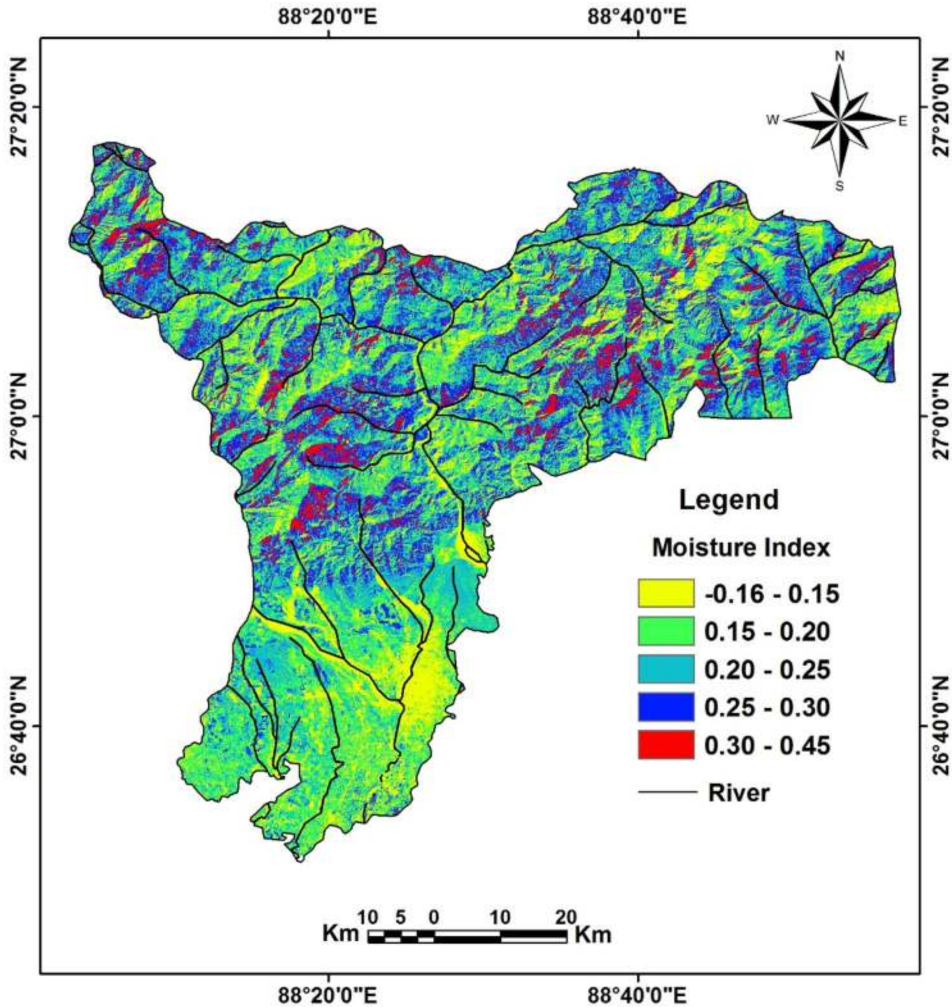

Fig. 11 Soil moisture map of the study area

analyzing the physical qualities/characteristics of these areas, it was explored that 55.78 % (175,669.57 ha) of the slope is higher than 20° slope, 60.89 % (191,767.14 ha) of the land cover area is under dense vegetation cover, 51.97 % (163,670.62 ha) lands is higher than 1000 m elevation, 45.19 % (142,318.17 ha) area is under triassic geological formation, 56.87 % (179,102.33 ha) lands is under dry soil, 50.64 % (159,482.02 ha) area is under coarse loamy to gravelly loamy in character in the study area. Also, it is well known that the local peoples utilise soil for their own means, to create terraces and carry out small amount of agricultural production on lands that are cureently and permanently unsuitable for agricultural production (Table 10).

Conclusion

The aim of this study was primarily focused on the identification of the suitable land for agriculture in the Darjeeling district which is mostly covered by tea cultivation and dense vegetation cover. Analytic hierarchy process with a combination of Geographic information system (GIS) is utilized for the evaluation in which nine different criteria were selected. The Analytic hierarchy process with integration of GIS was established very useful for the identification of the suitable site for agriculture. At the end of the evaluation, it was computed that only 5.31 % (16,722.94 ha) of the study area is mostly suitable for farming, and 40.60 % (127,862.76 ha) area is permanently

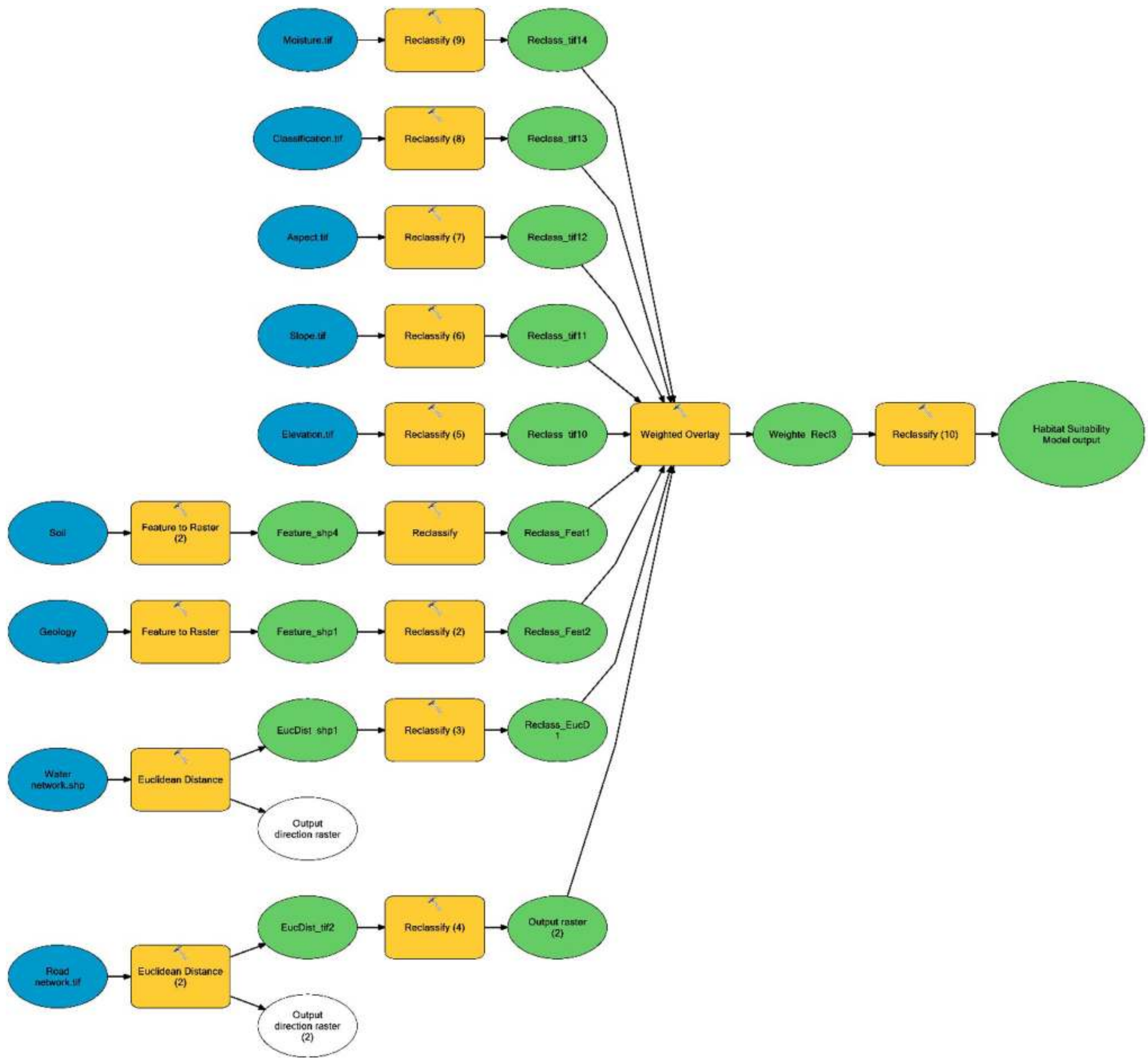

Fig. 12 Site suitability model for agriculture

and currently not suitable for agriculture production. However, the problems of the low production caused by geomorphological characteristics, such as very high elevation, a high degree of slope, less soil moisture, the presence of bare rocks, and low availability of the irrigation system. All these threats resulted in a very less amount of land in the study district being identified suitable for agricultural production.

The established result can be embraced by the decision-making process of the agricultural production in the study area, as it provides insight in establishing the suitable sites. The results can be more precise by

Table 3 Areal and percentile distribution of the selected criteria and sub-criteria in the study

Main criteria	Sub-criteria	Area (ha)	Area (%)
Slope (°)	0–3	48,184.73	15.30
	3–10	40,311.41	12.80
	10–20	50,767.18	16.12
	20–30	37,414.03	11.88
	30–89	138,255.54	43.90
Elevation (m)	15–150	53,916.51	17.12
	150–500	36,658.19	11.64
	500–1000	60,687.57	19.27
	1000–1500	48,468.17	15.39
	1500–3209	115,202.45	36.58
LULC	Agriculture	88,843.95	28.21
	Settlement	9297.81	2.95
	Water bodies	8936.82	2.84
	Sand deposition	3429.30	1.09
	Tea cultivation	12,657.87	4.02
	Vegetation	191,767.14	60.89
Soil moisture	<0.15	30,170.57	9.58
	0.15–0.20	35,807.87	11.37
	0.20–0.25	69,852.12	22.18
	0.25–0.30	167,890.72	53.31
	0.30–0.45	11,211.61	3.56
Distance from river (km)	0–0.5	45,066.90	14.31
	0.5–1.0	50,094.78	15.97
	1.0–2.0	73,127.42	23.22
	2.0–3.0	47,145.45	14.97
	3.0–8.3	99,298.34	31.53
Soil characteristics	Fine loamy to coarse loamy	107,801.53	34.23
	Coarse loamy	11,400.57	3.62
	Gravel loamy to coarse loamy	102,605.14	32.58
	Gravel loamy	41,445.17	13.16
	Gravel loamy to loamy skeletal	51,680.49	16.41
Geology	Holocene	63,553.46	20.18
	Pleistocene (middle–upper)	66,135.91	21.00
	Pleistocene to Pliocene	142,318.17	45.19
	Cainozoic	27,210.20	8.64
	Triassic	15,715.15	4.99
Aspect	SW, flat	119,674.50	38.00
	S, SE	60,246.66	19.13
	E,W	51,050.62	16.21
	NW, NE	44,090.60	14.00
	N	39,870.50	12.66
Distance from road (km)	0–1.0	78,985.17	25.08
	1.0–2.0	82,701.38	26.26
	2.0–4.0	96,117.52	30.52
	4.0–8.0	35,020.54	11.12
	8.0–12.7	22,108.29	7.02

Table 4 The fundamental scale for pairwise comparison matrix (Saaty 1980)

Importance rank	Definition	Explanation
1	Equal importance	Two criteria enrich equally to the objective criteria
3	Low importance of one over another	Judgments and experience slightly favor one criteria over another
5	Strong or essential importance	Judgments and experience strongly favor
7	Established importance	A criteria is strongly favored and its dominance established in practice
9	Absolute or high importance	The evidence favoring one criteria over another is of the highest probable order of affirmation
2,4,6,8	Intermediate values between the two adjacent importance or judgements	When adjustment is needed
Reciprocals	If criteria i has one of the above numbers designated to it when compared with criteria j, then j has the reciprocal value when compared with i.	

Table 5 Pairwise comparison matrix for multi-criteria decision problems

Criteria	Slope	Elevation	LULC	Soil moisture	Drainage	Soil	Geology	Aspect	Road
Slope	1	2	2	3	4	6	8	9	9
Elevation	1/2	1	2	3	4	6	7	9	9
LULC	1/2	1/2	1	2	3	4	5	7	8
Soil moisture	1/3	1/3	1/2	1	2	3	5	6	7
Drainage	1/4	1/4	1/3	1/2	1	3	5	6	7
Soil	1/6	1/6	1/4	1/3	1/3	1	1	2	3
Geology	1/8	1/7	1/5	1/5	1/5	1	1	1	3
Aspect	1/9	1/9	1/7	1/6	1/6	1/2	1	1	2
Road	1/9	1/9	1/8	1/7	1/7	1/3	1/3	1/2	1

Table 6 The synthesized matrix for multi-criteria decision making

Criteria	Slope	Elevation	LULC	Soil moisture	Drainage	Soil	Geology	Aspect	Road	Weights
Slope	0.323	0.433	0.305	0.289	0.270	0.242	0.240	0.217	0.184	0.278
Elevation	0.161	0.217	0.305	0.289	0.270	0.242	0.210	0.217	0.184	0.233
LULC	0.161	0.108	0.153	0.192	0.202	0.161	0.150	0.169	0.163	0.162
Soil moisture	0.108	0.333	0.076	0.096	0.135	0.121	0.150	0.145	0.143	0.117
Drainage	0.081	0.054	0.051	0.048	0.067	0.121	0.150	0.145	0.143	0.095
Soil	0.054	0.036	0.038	0.032	0.022	0.040	0.030	0.048	0.061	0.040
Geology	0.040	0.031	0.031	0.019	0.013	0.040	0.030	0.024	0.061	0.032
Aspect	0.034	0.024	0.022	0.016	0.011	0.020	0.030	0.024	0.041	0.024
Road	0.034	0.024	0.019	0.014	0.010	0.013	0.010	0.012	0.021	0.019

Maximum eigenvalue (λ_{max}) = 9.782

n = 9

Consistency index (CI) = $(\lambda_{max} - n)/(n - 1)$ = 0.0977

Random index (RI) = 1.46

Consistency ratio (CR) = (CI/RI) = 0.0669

Table 7 Random inconsistency indices (RI) for n = 10

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.46	1.49

Table 8 Weights of the criteria and scores of the sub-criteria

Main criteria	Weight	Influence (%)	Sub-criteria	Score
Slope (°)	0.278	27.8	0–3	10
			3–10	8
			10–20	6
			20–30	4
			30–89	2
Elevation (m)	0.233	23.3	15–150	10
			150–500	6
			500–1000	4
			1000–1500	2
			1500–3209	1
LULC	0.162	16.2	Agriculture	10
			Settlement	1
			Water bodies	1
			Sand deposition	1
			Tea cultivation	1
			Vegetation	1
Soil moisture	0.117	11.7	<0.15	1
			0.15–0.20	2
			0.20–0.25	6
			0.25–0.30	8
			0.30–0.45	10
Distance from river (km)	0.065	6.5	0–0.5	10
			0.5–1.0	7
			1.0–2.0	5
			2.0–3.0	2
			3.0–8.3	1
Soil characteristics	0.040	4.0	Fine loamy to coarse loamy	7
			Coarse loamy	5
			Gravel loamy to coarse loamy	3
			Gravel loamy	2
			Gravel loamy to loamy skeletal	1
Geology	0.032	3.2	Holocene	10
			Pleistocene (middle–upper)	7
			Pleistocene to Pliocene	5
			Cainozoic	3
			Triassic	1
Aspect	0.024	2.4	SW	10
			S, SE	9
			E,W	5
			NW, NE	3
			N	1
Distance from road (km)	0.019	1.9	0–1.0	10
			1.0–2.0	7
			2.0–4.0	4
			4.0–8.0	3
			8.0–12.7	1

Table 9 Areal and percentile distribution of agricultural land suitability analysis results

Suitability level	Suitable areas for agricultural production		Suitable areas within vegetation and tea garden (ha)	Areas to be inundated by the water bodies (ha)
	ha	%		
High suitability	16,722.94	5.31	5668.79	1259.73
Moderate suitability	93,912.99	29.82	20,470.64	9762.92
Marginally suitable	76,434.21	24.27	58,577.52	1196.74
Currently not suitable	120,241.38	38.18	112,116.11	125.97
Permanently not suitable	7621.37	2.42	7558.39	31.49
Total	314,932.89	100	204,391.45	12,376.85

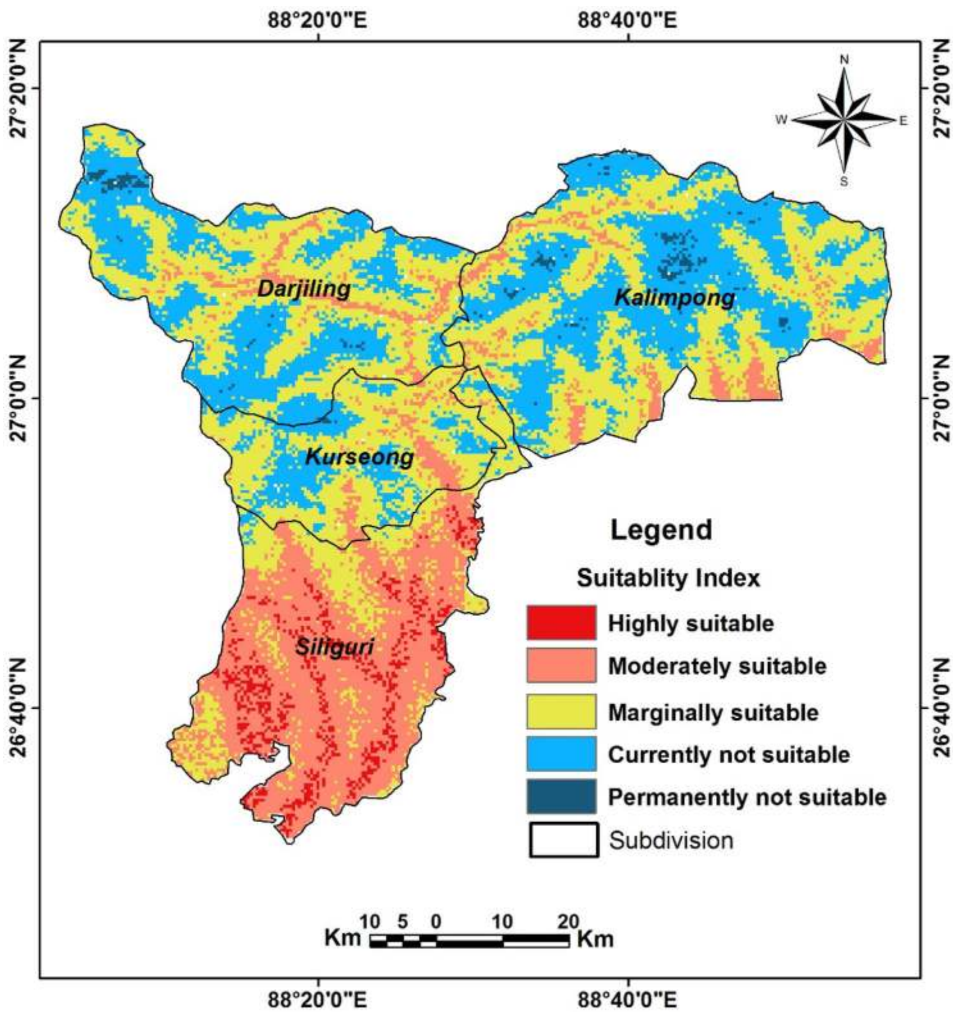

Fig. 13 Site suitability map for agriculture in Darjeeling district

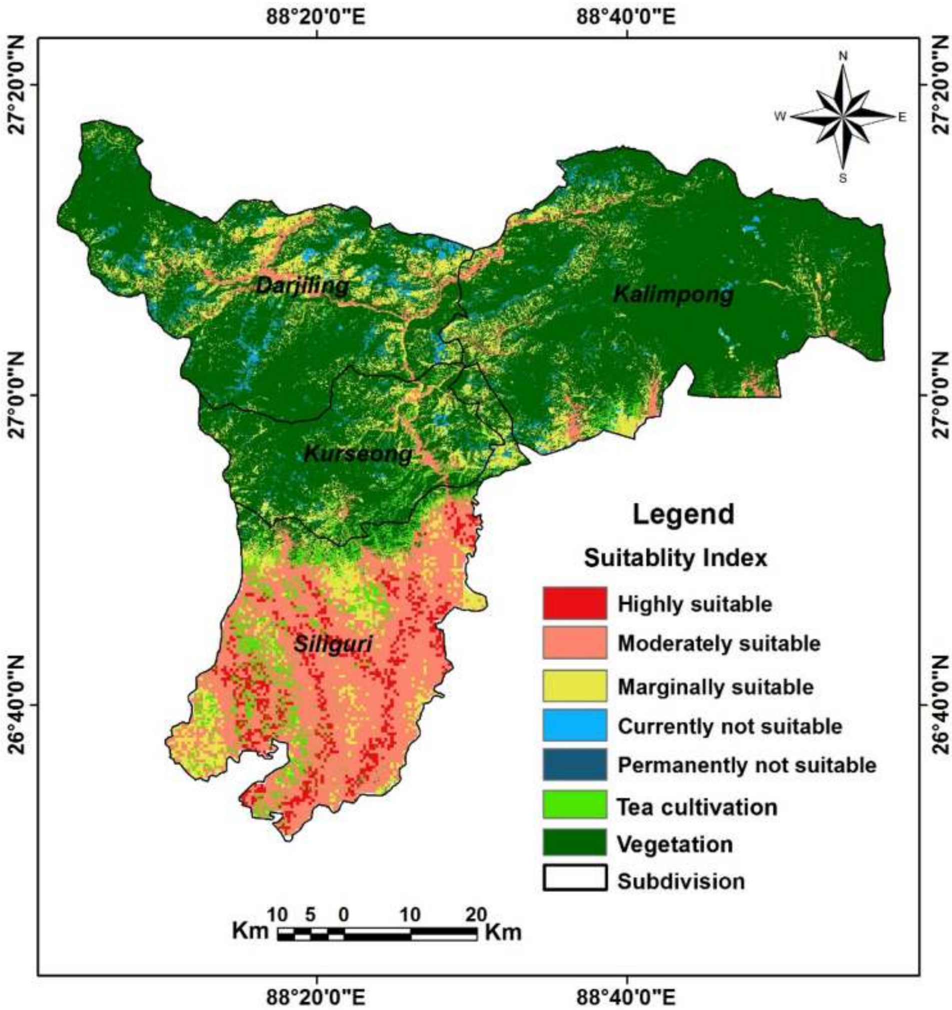

Fig. 14 Site suitability map obtained after removing vegetation and tea cultivated lands

critically analyzing the methods and techniques utilised. The study also comprises the physical properties (topographical properties, soil and geological characteristics, etc.) only and need to include the economic and social criteria for agricultural production. Since in analytic hierarchy process, the pairwise comparison method is established on expert opinions which are mostly subjective in nature. Therefore, any wrong judgement on the any selected parameters can be efficiently conveyed to the score assignment and weights designation. This is the prime drawback of the analytic hierarchy process, and hence, weights and scores need to be designated carefully (Kritikos and Davies 2011; Nefeslioglu et al. 2013). For more beneficial and accurate results the study demands to be emphasized on some important species, like several medicinal plants/species which have significant economic value and also influences the scope of progress in rural tourism too. The utilisation of very high-resolution satellite image will aid in evaluating more finer areas. Also, the identified areas have to be documented on ground level with some other local and regional parameter before the final implementation.

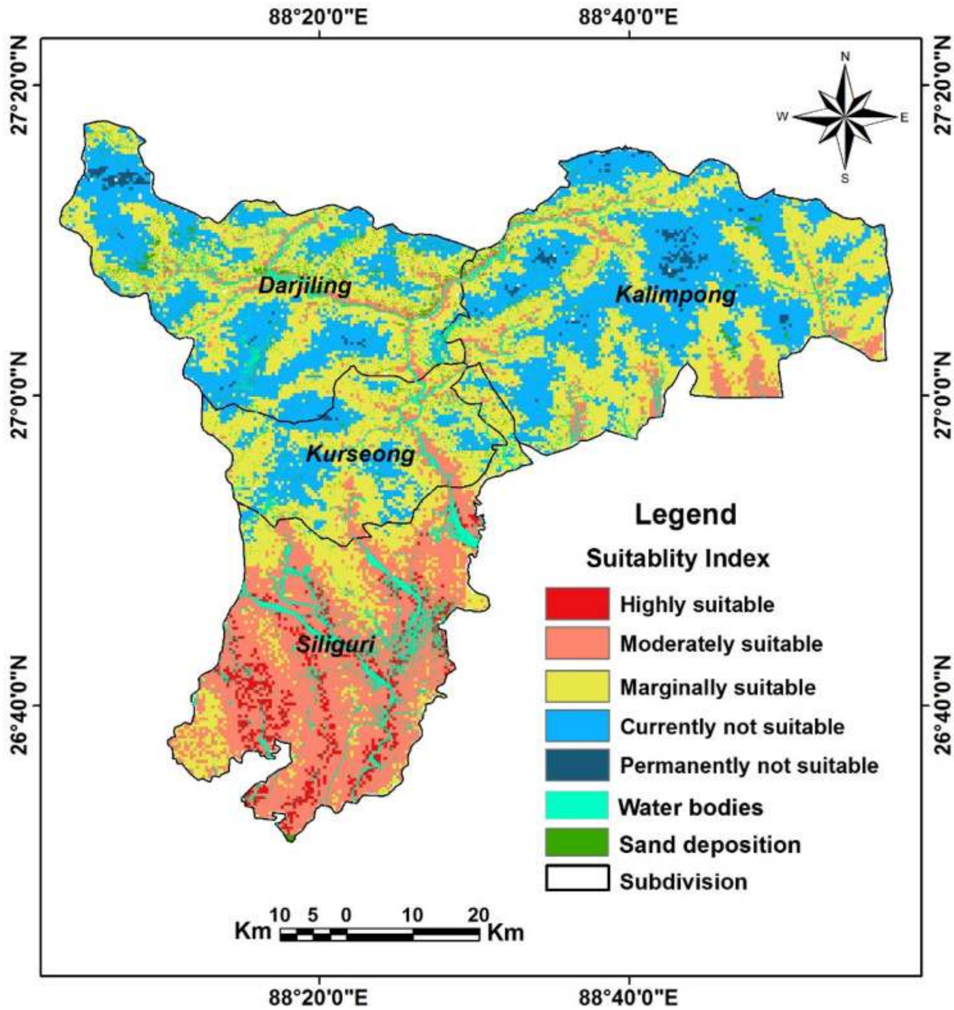

Fig. 15 Site suitability map obtained after removing water bodies and barren lands

Table 10 Land suitability levels and their land characteristics

Suitability classes	Subdivision wise distribution of land suitability (ha)		Land qualities/characteristics	Remarks
Highly suitable	Darjeeling	15.51	Gentle slopes (0°–3°) with gullies, high soil moisture with lower elevation, fine loamy to coarse loamy soil, good drainage capacity	Most suitable for agriculture, favorable area for intensive agriculture if irrigation facilities are available
	Kalimpong	153.85		
	Curseong	180.61		
	Siliguri	16,237.97		
Moderately suitable	Darjeeling	6799.30	Gentle to stiff slopes (3°–10°) with micro terracing, medium soil moisture with lower elevation, coarse loamy soil, moderate drainage capacity	Suitable land for farming practices with proper management, suitable for terrace cultivation
	Kalimpong	8705.73		
	Curseong	4028.87		
	Siliguri	74,379.09		
Marginally suitable	Darjeeling	25,605.46	10°–20° slope, less soil moisture with higher elevation, coarse loamy to gravel loamy soil, low drainage availability	Less suitable land for agriculture with careful farm management, necessary protections from drainage and intensive erosion
	Kalimpong	32,484.54		
	Curseong	13,146.68		
	Siliguri	5197.53		
Currently and permanently not suitable	Darjeeling	49,355.02	Precipitous slope with rocky lands, dry soil, dense forest, barren land, loamy skeletal soil, no drainage availability	The land is not suitable for agriculture, areas under dense vegetation, settlement, barren lands, open rocks are not suitable for agriculture
	Kalimpong	59,072.59		
	Curseong	17,900.79		
	Siliguri	1539.35		
Total	914,932.89			

Also, the study can be approved for rest of areas and also including other spheres of ecotourism than agriculture which can flourish in Darjeeling and its immediate surroundings.

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