



GIS and multi-criteria decision-making assessment of sites suitability for agriculture in an anabranching site of sooin river, India

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Abstract

In the study region, agriculture is the prime source of income, so it is very essential to make optimal use of existing agricultural land. To identify suitable sites for agricultural practices in the study area, the AHP model has been used. Due to the agricultural illiteracy, lack of irrigation and transportation facilities, human encroachment towards the agricultural land, and frequent flooding hampering agricultural productivity. A total of 16 parameters were taken into consideration and their weights are assigned according to their relative importance for identifying land suitability. The final suitability map of the study area has been generated using ‘Weighted Overlay’ method on GIS environment and classified into five categories as Very high suitable zone (4.11 per cent), High suitable zone (28.65 per cent), Moderate suitable zone (49.67 per cent), Low suitable zone (14.33 per cent) and Unsuitable zone (3.24 per cent). The Northern and Eastern parts of the study area are partially not suitable for agriculture. As the region is a flood plain fertile area, if the governments and other organizations take initiatives of improving transportation, soil management, flood control, then the area is highly promising of agricultural productivity. As the GIS-based AHP model is a simplified and suitable method for site suitability analysis, this paper will help the policymakers implement different plans for the development of the region.

Keywords Sooin river · Agriculture land suitability · AHP · GIS

Introduction

Agriculture is the most primordial occupation of civilized modern human society (Prakash 2003) but after the industrialization (Chuanmin and Falla 2006), the pattern of agriculture has been changed to facilitate the increasing food demands due to rapid positive growth in population density and demand (Yalew et al. 2016; Lambin and Meyfroidt 2011). In recent times, global land resources and its

productivity are declining day by day though their demand is showing an increasing trend (Cowie et al. 2018). The developing countries such as India and Bangladesh, the national economy is primarily based on agriculture (Swaminathan 2007). Agricultural productivity is determined by different factors such as fertility of the soil, favorable climatic condition, proper irrigation facilities, developed transportations, knowledge about agriculture, availability of the modern machinery, and accessibility to the markets. For agricultural development, the 1953 Indian Council of Agricultural Research classified India into 8 major and 26 minor categories based on their ‘Soil formation’, ‘Soil Character’, ‘Vegetation cover’, ‘Bed-rock Structure’, and ‘Climatic variation’ (ICAR 2020).

The census 2011 reported that in India, the Agriculture sector provides 58 per cent livelihood of the total population and it accounting for about 16 per cent of the country’s GDP. In India, this sector is facilitating employment to 54.6 per cent of the gross workers (MAFW, GOI 2011). Whereas, the state of West Bengal was produced over 8 per cent of the gross food production of the nation (<https://matirkatha.net/>). In West Bengal, 19.53 per cent, and 19.30 per cent

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are cultivators and agricultural laborers, whereas 68.13 per cent of the total population lived in the rural areas and the majority of them are agricultural laborers (NABARD 2013).

Agriculture is the source of the ‘food’ and ‘fodder’ to the human and livestock population. The function of agriculture is multi-factorial as it plays an essential role in the development of the socio-economic status of rural India. After the ‘Green Revolution’, the agricultural productivity in India observed tremendous growth but lack of agricultural knowledge and unparalleled use of ‘fertilizers’, ‘pesticides’, the productivity of the soil is increasingly decreased and the soil erosion is also a common phenomenon in Indian agriculture. To avoid such problems, agricultural reforms have been done over time to time and organic farming is considered to be the lifesaver in the agricultural field (Lapple and Cullinan 2012). Industrialization, urbanization, and human encroachment towards arable lands modify the ‘Natural Landscapes’ and creates an ecological misbalance and environmental problems (Boori et al. 2015). It is very essential to use the agricultural and other lands scientifically that the ecosystems remain undisturbed.

The land is a unique constituent and land users are negatively or positively affected (Rossiter 1996) its uniqueness. ‘Agriculture land suitability’ analysis is an inter-disciplinary approach and it is a determination of optimum land use form and type of a given region. To determine the suitable land for agriculture, an affective measure is required because of unplanned land use patterns may create urban (Ullah and Mansourian 2015) as well as rural environmental problems and degradation. Land suitability is an ability of the soil to support a definite land use pattern. The Land Suitability Analysis (LSA) is an environmentally friendly procedure to encounter the intrinsic and potential capabilities of the land of any region (Bandyopadhaya et al. 2009). The main objective is to predict the inherent capability (Rosa and Sobral 2008) of a land unit to support a specific land use pattern. Land suitability is the fitness or comfort level of a given area for a specific land use type or it is the degree of satisfaction of the land user. The process of LSA can be both quantitative and qualitative and the scope of suitability is the current (present condition) and the potential suitability (predicted pattern) (FAO 1976; Prakash 2003). The land suitability is a measure to discover the degree of land usefulness for potential or future land use form (FAO 1976; Malczewski 2004; Hopkins 2007). It is a measure that helps to explore the qualities of the land unit and how that land unit fulfills the requirements of a particular land use pattern. AHP is a very famous and well-accepted quantitative method to analyze the site suitability and it includes the hierarchical structure of the decision factors and constructs comparisons among the possible pairs in a matrix to give a weight to each factor (Bagherzadeh 2014; Daneshvar 2014; Daneshvar et al. 2017). Literature suggested that the AHP

method is frequently used by several researchers to explore the suitable sites as per their requirements. Some of the AHP method-based site suitability works are the reorganization of tourist zones (Ebrahimi et al. 2019), Land suitability for paddy cultivation (Kihoro 2013; Roy and Saha 2018; Mandal and Saha 2019), Site suitability analysis for agricultural land use (Pramanik 2016; Tuyen et al. 2019), Potential land suitability identification for surface irrigation (Teshome and Halefom 2020), Land Suitability and agricultural production sustainability (Amini et al. 2019; Prakash 2003), Suitability analysis for water conservation (Badhe et al. 2019), Suitability for sewage treatment plant (Agarwal et al. 2019), Identification of soil erosion-susceptible areas (Saha et al. 2019), Plantation development (Zolekar and Bhagat 2014; Uristiati et al. 2020), for construction avulsion potential zone (Sarkar and Pal 2018), suitable site selection for rainfed teff crop production (Kahsay et al. 2018), hospital site selection (Halder et al. 2020), agricultural site selection in Abbay basin (Yalew et al. 2016), for Selecting Potential Sites for Water Harvesting (Alshabeeb 2016). The AHP-based site suitability analysis is more prominent as it allows researchers to the measurement of the relative weights of each criterion or parameter according to their relative importance (Bani 1989; Akinci 2013). The priority values of the parameters are also been measured by the decision-making process (DMP) to explore suitable locations with several alternatives (Wang et al. 1990; Jankowski 1995; Yu et al. 2011).

In site suitability analysis, the ‘Geographic Information System’ (GIS) is a much indispensable technique to analyze and to investigate the various geospatial parameters with a high degree of flexibility (Mokarram and Aminzadeh 2010; Mendas and Delali 2012). Moreover, GIS has scientific credibility, capability for determining the suitability of the site on a given purpose (Baban 1998; Chandio 2012). Augment the Multi-Criteria Analysis (MCA) as a decision support tool, it can be incorporated along with the GIS to combine geospatial data with multiple criteria decision models (MCDM) to produce final site suitability map (Carver 1991; Malczewski 2006). This approach can help the prompt and faster rate of remodeling of tiny changes for criteria to fabricate results in the form of maps for presentation (Parker 1996), i.e. the combination of GIS and AHP is a dominant tool for assessing of land site suitability (Malczewski 2006; Duc 2006).

Study area

The study area is located in the border sites of West Bengal and Bihar states of India where over 95 per cent of the study area is situated at Uttar Dinajpur District in the state of West Bengal. The geographical extension of the study area is 25°15′40.42″N to 25°32′43.27″N and 88°02′32.13″E to 88°09′47.86″E and the total geographical area is about

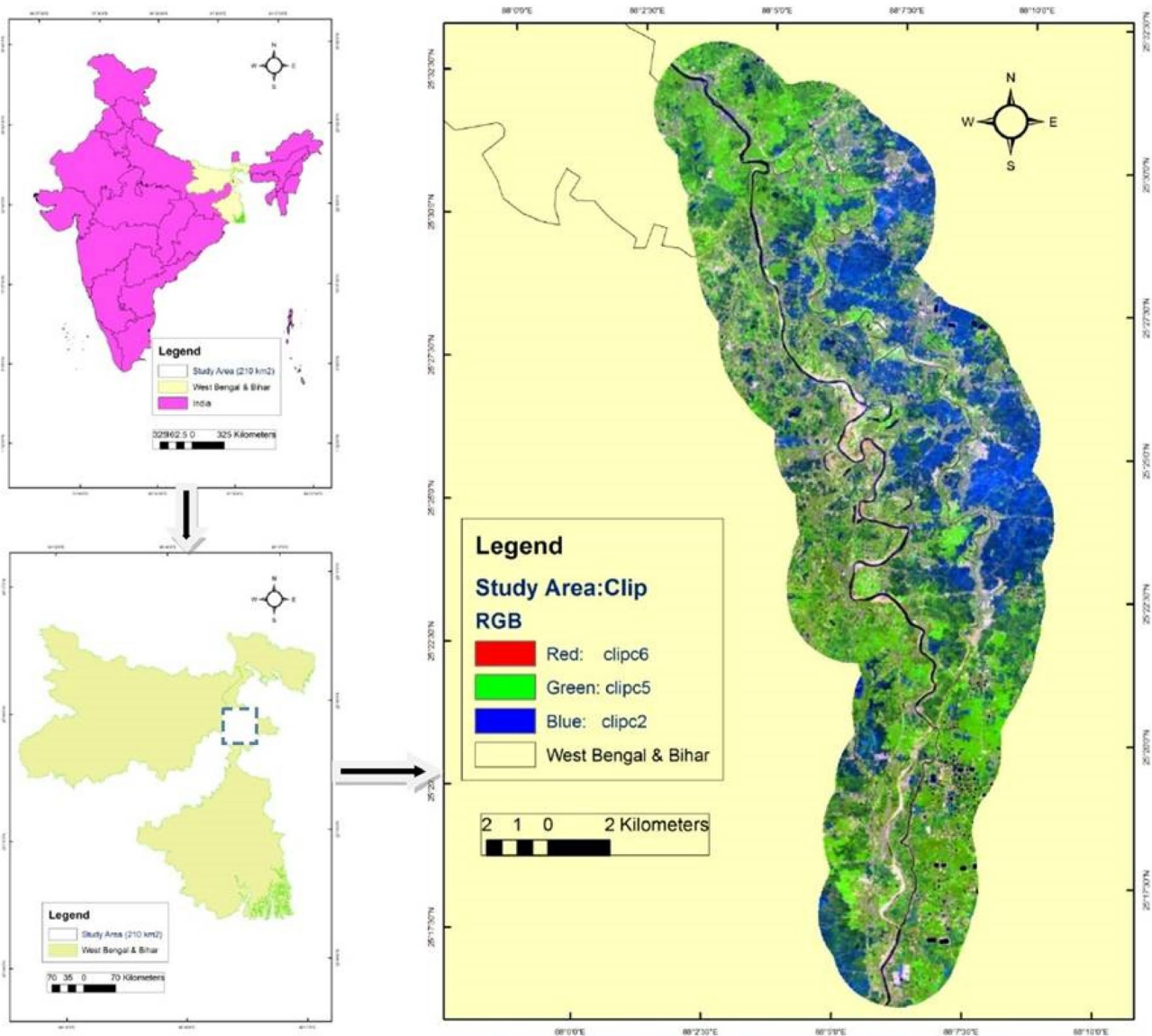


Fig. 1 Geographical location of the study area

210 sq.km (Fig. 1). Climatologically, the study area is under humid subtropical climatic and the annual average temperature of the study area ranges between a minimum of 7 °C to a maximum of 39 °C. Along the north to south longitudinal elevation line, the study area experiences a maximum slope deviation of 3.5–3.6 per cent with an average slope deviation of 0.7–0.8 per cent per km. The NH-34 road extended from north to south along the eastern margin of the study area. The study region is situated in an anabranching site of the Sooin River and characterized by a new alluvial flood plain. Every year during the rainy period, flooded water deposited fertile soil over the region which promotes high productivity in the study area. Agriculture is a major economic activity

and its estimated values show that about 37.05 per cent is presently cultivated with seasonal (Wheat, Maize, Mustard, etc.) crops and 20.06 per cent are single crops land.

Objectives of the study

The main objectives of the present study are.

1. To the assessment of agriculture affecting parameters in the selected study area,
2. To determine the priority values of the selected parameters using AHP,
3. Identifying suitable sites for agriculture using AHP and GIS.

Materials and methods

Data source

For preparing the individual parameters, both the field survey data and secondary data have been collected from different sources (Table 1). Landsat-8 satellite map was collected from the ‘USGS’ or ‘United States Geological Survey’ (<https://earthexplorer.usgs.gov/>) for analyzing the ‘LST’, ‘MSAVI’, ‘MNDWI’, ‘LULC’. The ‘Slope’, ‘Aspect’, and ‘Elevation’ data are extracted from the ‘Shuttle Radar Topography Mission’ (STRM) near-global Digital Elevation Models (DEMs) data of 30 m resolution obtained from United States Geological Survey (USGS). Rainfall data have been collected from the ‘CHRS’, and ‘NASA’ data portal and verify it with the ‘IMD’ (Indian Meteorological Department) dataset. Manual digitization in Google Earth has been done for preparing the ‘Road Network’ and ‘Drainage Network’ of the study area. The ‘lithological’ information and data have been gathered from the Geological Survey of India (bhukosh.gsi.gov.in/). Soil properties such as ‘Bulk Density’, ‘Cation Exchange Capacity’, ‘Soil Texture’, ‘Soil pH’, and ‘Soil Organic Carbon’ were collected from ‘Soil Grid’ (<https://soilgrids.org/>) dataset and also verify it with soil samples that were collected during the field verification.

In the present study, the multi-criterion site suitability model was applied for identifying the potential sites for agriculture practices. A total of 16 parameters have been taken for constructing the land suitability map of the study area. After selecting the parameters the criteria pair-wise comparison matrix was calculated using the AHP method, the parameters were rearranged in hierarchical order to compute a normalized pair-wise comparison matrix from it. From the normalized pair-wise comparison matrix, the ‘Weighted Sum Vector’ (WSV) was computed to find out the ‘inconsistency’ in the matrix. The ArcMap-10.5

environment was used to generate the final suitability map. According to the ‘FAO’, land suitability for agriculture or farming can be classified as Highly Suitable—S1, Moderately Suitable—S2, Marginally Suitable—S3, Currently not Suitable—N1, and Unsuitable—N2 zone. Based on the FAO’s classification, the final suitability map of the study area has also been categorized into five expected zones where the least value indicates the very less suitability or unsuitability for agricultural activities and vice-versa. The flowchart and the adopted weighted overlay model for the present study are given in Figs. 2 and 3 respectively.

Generation of criterion maps using geospatial techniques

Slope (Fig. 4a), Aspects (Fig. 4b), and Elevation (Fig. 4c) layers were generated in ArcGIS 10.5 environment. The Thematic layer of the ‘Rainfall’ (Fig. 4d) was constructed using the grid method. For constructing the ‘Temperature’ layer, the ‘LST’ (Fig. 4e) was generated from the average ‘LST’ values of ‘Band-10’ and ‘Band-11’ of Landsat-8 images. The LULC map (Fig. 4f) was prepared from Landsat-8 image adopting supervised classification along with the ‘Maximum likelihood’ classifier algorithm and the accuracy was measured by the Kappa coefficient (86 per cent). ‘MNDWI’ for ‘Soil moisture’ (Fig. 4g) and ‘MSAVI’ (Fig. 4h) for ‘Vegetation cover’ and ‘soil moisture’ analysis was generated from the Landsat-8 imageries. ‘MNDWI’ and ‘MSAVI’ were engendered after correcting the reflectance value with local sun elevation angles for an accurate result. To analyze the soil moisture, MNDWI and MSAVI were calculated with the help of Eq. 1 and 2. The distance from the river and distance from road layers (Fig. 4i and 3j) was prepared by applying the ‘Euclidean distance’ buffering tool under ‘Spatial Analyst Tools’ in the ArcGIS-10.5 environment. ‘Lithology’ (Fig. 4k) layer was derived from Bhuvan datasets and analyzed it for litho-logical exploration of the study area. Soil properties map layers such as ‘Soil Texture’

Table 1 Materials and data source of the parameters

Parameters	Data information	Source	Resolution (m)
Topographic map	73C/2,73C/3 SOI	Soinnakshe.uk.gov.in	–
Geology	GSI, Bhukosh	www.gsi.gov.in	30
Slope, elevation, aspects,	SRTM DEM and Arc-GIS	Earthplor.usgs.gov	30
Soil characteristics	Bhuvan; World Soil Grid Datasets	Bhuvan.nrsdc.gov.in and Soilgrids.org	30
Soil moisture, MSAVI	IR and Green band of OLI image	Landsat-8 images	30
Drainage and roads	Digitized from Google Earth pro; Toposheets	Soinnakshe.uk.gov.in and Google-earth pro	30
LULC	OLI images and Arc-GIS	Landsat-8 images,	30
Rainfall and temperature	CHRS datasets, NASA, IMD	Power.larc.nasa.gov/data-access viewer and chrsdata.eng.uci.edu	30

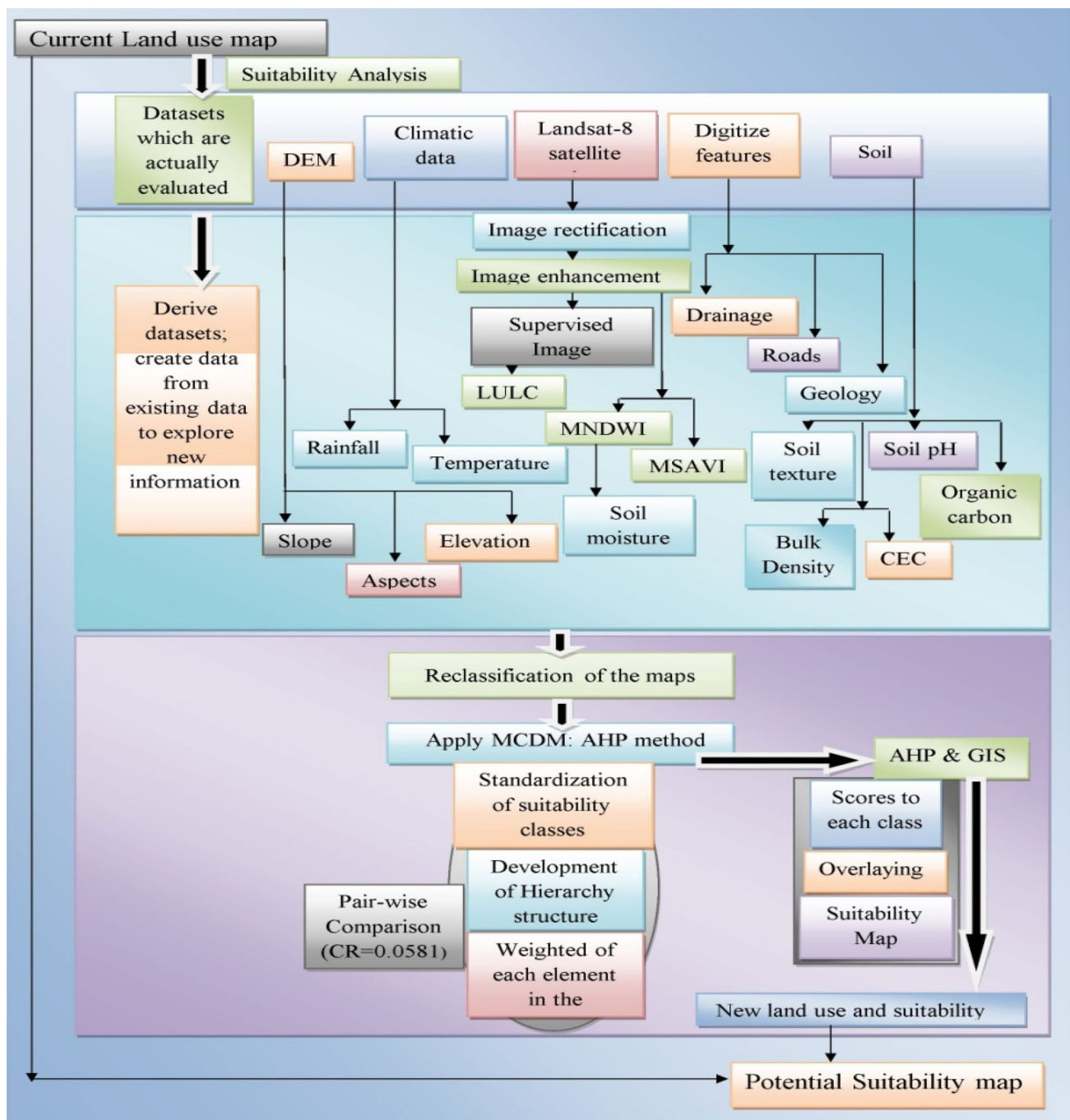


Fig. 2 Framework of the present study

(Fig. 4l), ‘Bulk Density’ (Fig. 4m), ‘Soil CEC’ (Fig. 4n), ‘Soil pH’ (Fig. 4o) and ‘Organic Carbon’ (Fig. 4p) were prepared from Soil Grids datasets combined with Bhuvan and Geological Survey of India (GSI) dataset.

$$MNDWI = \frac{Band3 + Band6}{Band3 - Band6} = \frac{GREEN - SWIR}{GREEN + SWIR}, \quad (1)$$

where MNDWI = Modified Normalized Difference Water Index; SWIR = Short Wave Infrared Radiation.

$$MSAVI = (1/2) * (2(B5 + 1) - \sqrt{(2 * B5 + 1)^2 - 8(B5 - B4)}), \quad (2)$$

where MSAVI = Modified Soil Adjusted Index; B5 = Pixel values from the near-infrared band; B4 = Pixel values from the red band.

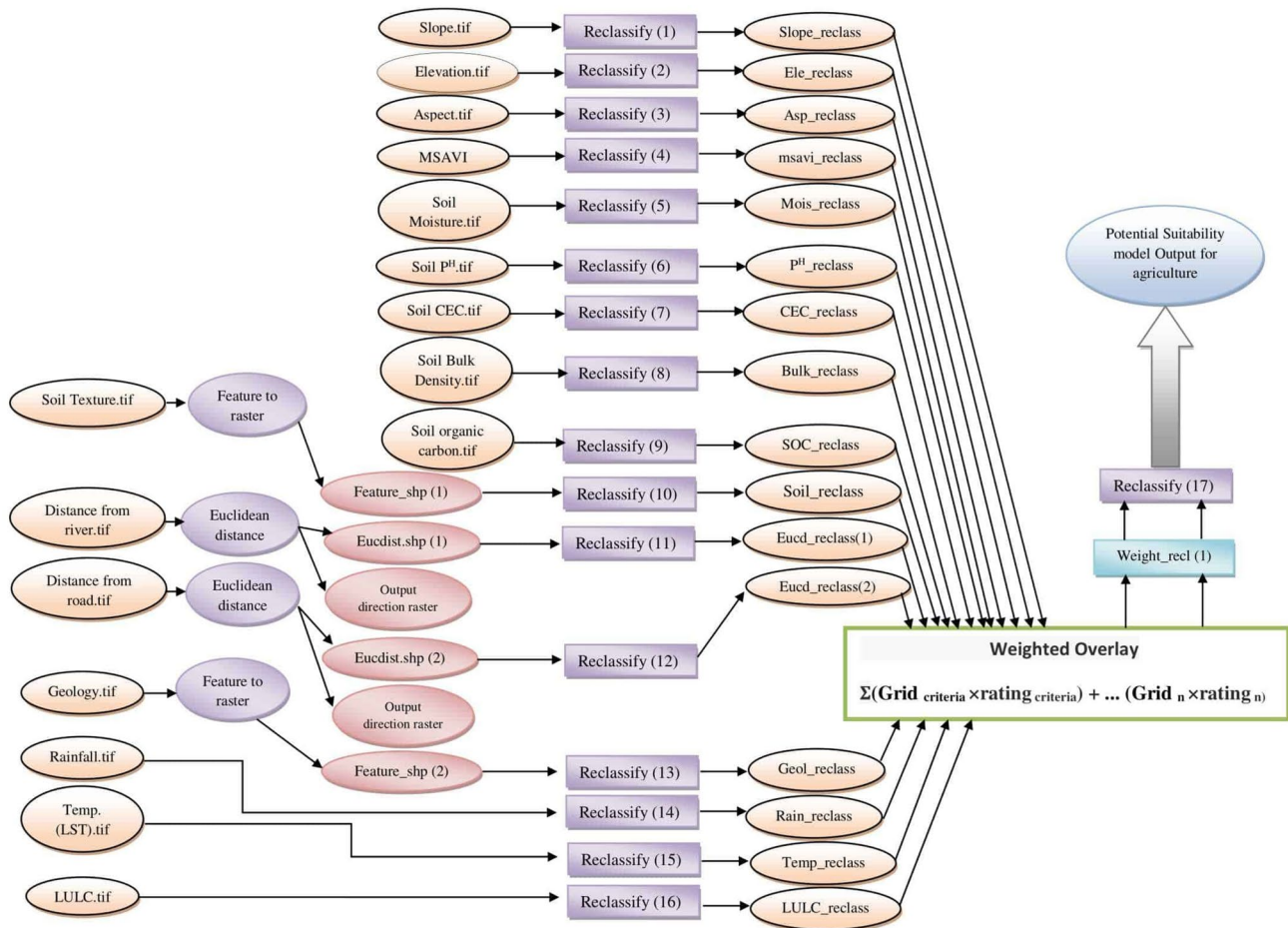


Fig. 3 Weighted overlay model of the present study

Standardization of the selected parameters

The final agricultural land suitability map was constructed by performing the weighted overlay model. For this purpose, the selected parameters or criteria were standardized. All the vector layers converted to the rasters to optimize the analysis process. All the converted raster layers then reclassified using AHP priority values to generate suitable locations for agricultural activities. The final output map is then categorized into five different classes. All the related map layers have been reclassified on Arc-Map.v.10.5 software as per their comparative hierarchical significance towards land use suitability. All the numerical calculations of the individual parameter are separately calculated using 'AHP' methods in Microsoft excel v.16. Studies show that every factor is related to each other and has an impact on each other. Assigning weights to the criteria is very essential as it defines the hierarchical importance of the criteria.

Assigning weights to the parameters

In multi-criteria decision-making purposes, researchers extensively used the GIS platform along with the AHP method (Joerin et al. 2001 Xu 2012). This semi-quantitative method was introduced by Thomas L. Saaty in (1977) to develop a hierarchal model for elaborating complex problems of land management with the most suitable alternatives (Malczewski 2006). AHP allows incorporated GIS-based land suitability modeling for site suitability (Alshabeeb 2016). Through AHP method, to achieve the goal of the study, various criteria are identified and divided into different alternatives, rearranging them in the most suitable hierarchical order (Cancela 2015), making a judgment from the relative importance of the parameters, and synthesizing the potential result (Saaty 1980, 1990, 2001). A complex problem actually is a set of several simple micro-problems that are also related to each other. In this method, the complex problem is breaking down

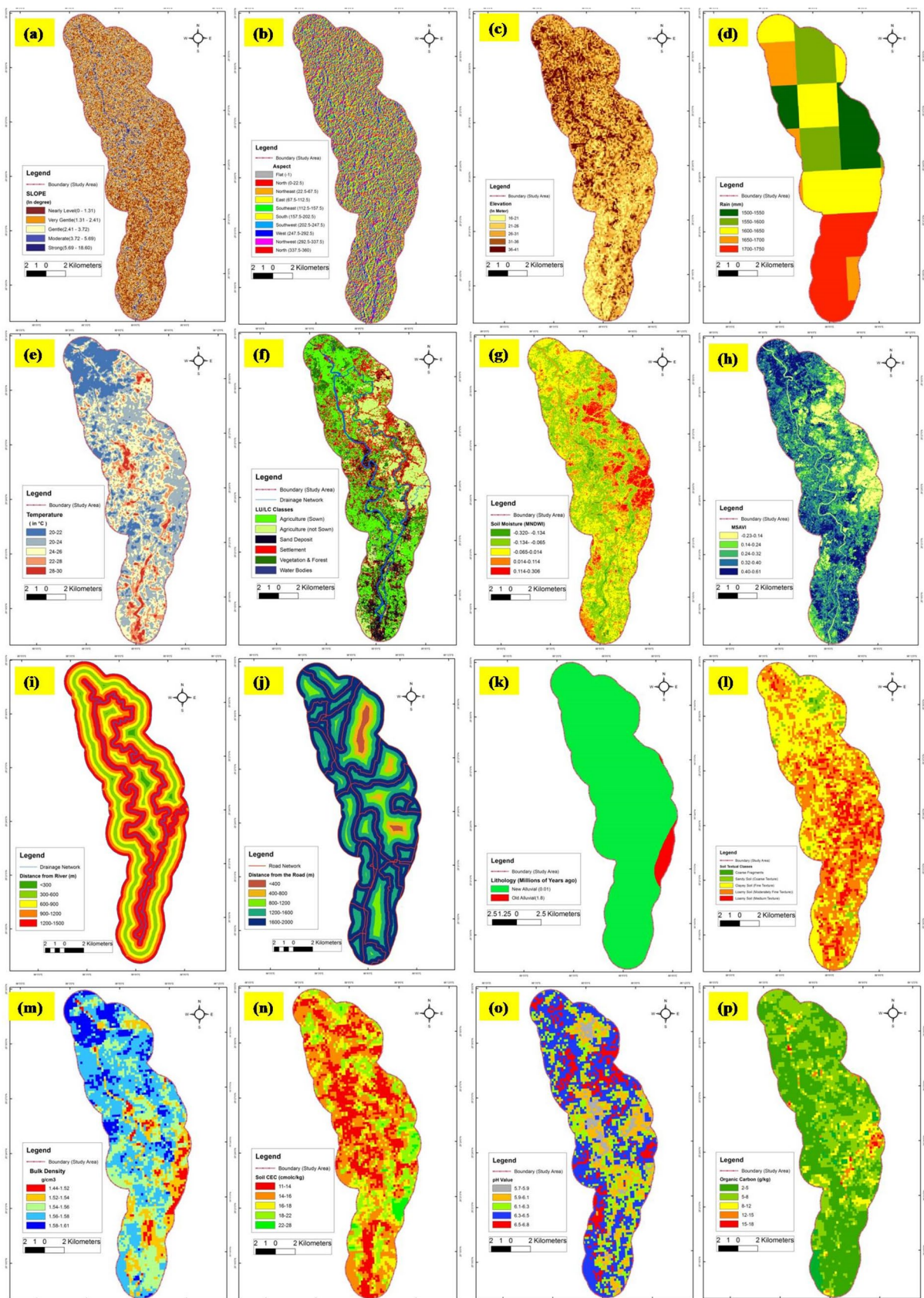


Fig. 4 a–p Spatial layers for preparing agricultural suitability zone; **a** Slope, **b** aspects, **c** elevation, **d** rainfall, **e** temperature, **f** LULC, **g** soil moisture, **h** MSAVI, **i** distance from river, **j** distance from road, **k** lithology, **l** soil texture, **m** bulk density, **n** soil CEC, **o** pH, **p** organic carbon

Table 2 The AHP Scale for paired comparison (Saaty and Vargas 2000–2001)

Index	Definition	Index	Definition
1	Equally important	1/1	Equally important
2	Equally or slightly more important	1/2	Equally or slightly less important
3	Slightly more important	1/3	Slightly less important
4	Slightly to much more important	1/4	Slightly to much less important
5	Much more important	1/5	Much less important
6	Much to far more important	1/6	Much to far less important
7	Far more important	1/7	Far less important
8	Far more important to extremely more important	1/8	Far less important to extremely less important
9	Extremely more important	1/9	Extremely less important

Table 3 Pair-wise comparison matrix

	Cn	c1	c2	c3
A1	c1	cXij1	cXij1/2	cXij1/3
	c2	cXij2	cXij1	cXij2
	c3	cXij3	cXij1/2	cXij1

into various smaller problems (Azizi et al. 2014) with suitable hierarchal order. This method allows quantifying options and transforming the options into a coherent decision model. In AHP, the matrix classification is based on the 1–9 scale of relative importance, where level 1 represents an ‘Equally important’, and level 9 shows ‘Extreme importance’ (Saaty 1977; Feizizadeh and Blaschke 2013; Table 2).

The elements of the pair-wise comparison matrix can be expressed as the following matrix (Table 3).

Where, A1 = Pair-wise Comparison Matrix; Cn = Name of the Criteria; Xij = Performance Value of each cell.

After completing the pair-wise comparison matrix, each cell value i.e. performance score of each cell was divided by the sum of that specific criteria column to normalized the pair-wise comparison matrix table (Saaty 1980; Feizizadeh 2014; Malczewski 1999). From the normalized matrix table, the relative priority value of each criterion was calculated using saaty’s method. In this study, the eigenvector method was applied to estimate the weight of each criterion from the normalized pair-wise comparison matrices table. After calculating the priority decision matrix, the ‘Weighted Sum Vector’ was estimated to find out the inconsistency among the parameters because there may be some inconsistency in the result due to random matrix formation (Saaty 1980, 1990, 1994). Equation 3 was used for estimating this inconsistency (Saaty 1980; Feizizadeh 2014; Garcia et al. 2014).

$$WSV = \sum_{j=1}^n w_j * x_{ij}, \tag{3}$$

where WSV = Weighted Sum Vector; wj = Weight of each parameter; xij = Performance Value of each criterion (from the primary pair-wise matrix).

$$CR = \frac{CI}{RI}, \tag{4}$$

where CR = Consistency Ratio; CI = Consistency Index; RI = Consistency index for a random square matrix of the same size (Table 4).

Table 4 Random Consistency Index (RI) for n = 10.

CR value was calculated using Eq. 4. CR value should be lower than or equal to 10 per cent or 0.1, because CR value indicates the acceptability of the weighting process of the parameters. If CR is less or equal to 10 per cent, the weighting process incorporated with the whole analysis and the result will be meaningful (Saaty 1982) and if the value is more than 10 per cent than the variables will be omitted i.e., weighting of the criterion wasn’t suitable or efficient to proceed the analysis. The CR value depends on the Consistency Index and Random Index (Table 4) and it is the ratio between CI and RI. CI was estimated from the average value of Consistency Vector (Eq. 5, Eq. 7) which is the ratio of ‘Weighted Sum Vectors’ and ‘Criteria Weights’ or ‘Criteria values’.

$$CV = \left[\frac{wsv1}{cw1}, \frac{wsv2}{cw2}, \frac{wsv3}{cw3} \right], \tag{5}$$

where CV = Consistency Vector; WSV = Weighted Sum Vector; CW = Criteria Weight. From the Consistency Vector (CV), the value of lambda (λ) was computed. Lambda is the average value of the consistency vector i.e. it is the highest

Table 4 Random Consistency Index (RI) for n = 10

n (Size of matrix)	1	2	3	4	5	6	7	8	9	10
RI (Random Consistency Index)	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Eigen value of the matrix (Saaty 1977). The ‘ λ_{max} ’ and ‘CI’ were calculated using Eq. 6 and 7, respectively.

$$\lambda_{max} = \frac{cv1 + cv2 + cv3 + \dots + cvn}{\text{no.of criteria}} \quad (\text{CV} = \text{Consistency Vector}), \tag{6}$$

$$CI = \frac{\lambda_{max} - n}{n - 1}, \tag{7}$$

where λ_{max} = Highest Eigen value; n = No. of the Parameters or Size of the comparison matrix (Saaty 1980, 1982).

The value of the Consistency Index depends on the value of lambda (λ_{max}). The larger value of lambda (λ_{max}) indicates high inconsistency, i.e., with increasing the value of lambda (λ_{max}), the ratio of inconsistency is also be increased and vice-versa. Consistency Index was calculated using Eq. 7. Accurate pair-wise matrix and accurate weight of the alternatives or criteria leads a CR value ‘0’ which means the result is perfectly consistent and in this case, the lambda (λ_{max}) will be at a minimum or equal to ‘ n ’.

Generation of agricultural suitability zone (ASZ) using GIS technique

A hierarchical organization of the criteria or alternatives is very common in large decision-making problems (Prakash 2003). In AHP, all the criteria are classified into several alternatives and assigning rating value or criteria weights to each alternative according to their relative importance (Table 5). After assigning weights, all the raster layers and classes were overlaid to develop a final site suitability map (Eq. 8) (Fig. 3) (Ebrahimi et al. 2019). This final raster output map was generated in the ArcGIS environment using Eq. 9.

$$SZ = \Sigma(\text{grid criteria} \times \text{rating criteria}) + \dots (\text{grid } n \times \text{rating } n), \tag{8}$$

$$\begin{aligned} \text{ALSZ} = & \Sigma(\text{grid Slope} \times 0.064) + (\text{grid Elevation} \times 0.060) + (\text{grid Aspects} \times 0.032) + (\text{grid Rain} \times 0.076) \\ & + (\text{grid Temperature} \times 0.035) + (\text{grid Soil texture} \times 0.066) + (\text{grid pH} \times 0.060) \\ & + (\text{grid Organic carbon} \times 0.051) + (\text{grid Soil CEC} \times 0.045) + (\text{grid Bulk density} \times 0.037) \\ & + (\text{grid River} \times 0.130) + (\text{grid Road} \times 0.120) + (\text{grid Geology} \times 0.041) + (\text{grid MNDWI} \times 0.042) \\ & + (\text{grid TWI} \times 0.039) + (\text{gridLULC} \times 0.101). \end{aligned} \tag{9}$$

Table 6 Lithology of the study area

Category	Formation	Characteristics
New alluvium	Malda	Sand, silt and gravel
	Malda	Sand, silt and gravel
	Kosi-Ganga	Sand, silt and clay
Old alluvium	Baikunthapur	Sand, clay with calcareous concretions

Result and discussion

This region is a ‘fluventic’ soil zone, where 97.08 per cent area sedimented with new alluvium (Table 6). The soil in this region is very productive with optimum ranges of pH values from 5.5 to 6.5. Though some of the northern and eastern parts are formed with older ‘Pleistocene alluvium’ (2.92 per cent) which is less productive due to deficits in fertile minerals and high bulk density (Table 7).

The slope map of the study area has been classified into Very low (0° – 1.31°), Low (1.31° – 2.41°), Moderate (2.41° – 3.72°), High slope (3.72° – 5.59°) and Very High slope (5.59° – 18.60°) (Fig. 4a, Table 8). Overall, the longitudinal slope of the study area is north to south direction and the transversal slope of the study area is west to east direction. Aspects (Fig. 4b) are the orientation or compass of the slope of any region and it is a vital factor in suitability analysis for hilly regions but it can also be applied in the plain region. In this study, all the alternatives of the aspect have been almost equally important in suitability analysis. Most of the study area comes under very low-to-moderate slope zones which facilitate the ideal conditions for different crop production, although this region recorded a huge amount of crop loss in monsoon times. The altitude of the study varies from a low of 16 m in the south to the highest of 41 m in the west part of the study area (Fig. 4c).

Table 5 Soil texture with ideal bulk density

Names of the soils	Textural class	Diameter (mm)	Ideal bulk density (g/cm ³)
Coarse fragments			
Sandy soil (coarse texture)	Sand, loamy sand	Clay (0.0002)	< 1.6
Clayey soil (fine texture)	Clay	Silt (0.02–0.0002)	< 1.4
Loamy soil (moderately fine texture)	Sandy loam	Sand (2.00–0.02)	< 1.1
Loamy soil (medium texture)	Loam, silt loam, silt		

Table 7 Normalized pair-wise comparison matrix of each criterion with sub-criteria

Slope (degree)	Very low	Low	Moderate	High	Very high	Rating	Distance from river (m)	Very low	Low	Moderate	High	Very high
Very low (0–1.31)	1	2	2	2	5	0.348	Very low (0–267)	1	1	2	4	5
Low (1.31–2.41)	1	1	2	2	4	0.287	Low (267–534)	1	1	2	3	4
Moderate (2.41–3.72)	0.5	0.5	1	2	2	0.17	Moderate (534–801)	0.5	0.5	1	1	2
High (3.72–5.59)	0.5	0.5	0.5	1	2	0.127	High (801–1069)	0.25	0.33	1	1	1
Very high (5.59–18.60)	0.2	0.25	0.5	0.5	1	0.069	Very high (1069–1336)	0.2	0.25	0.5	1	1
CI=0.012; CR=0.011							CI=0.018; CR=0.016					
Aspects	SW	S,SE	E,W	NW,NE	N	Rating	Distance from road (m)	V. low	Low	Moderate	High	Very high
SW	1	1	3	4	5	0.362	Very low (0–378)	1	2	2	4	5
S,SE	1	1	2	4	5	0.333	Low (378–757)	0.5	1	2	4	5
E,W	0.5	0.33	1	2	2	0.149	Moderate (757–1136)	0.5	0.5	1	2	3
NW,NE	0.33	0.33	0.5	1	2	0.093	High (1136–1515)	0.25	0.25	0.5	1	1
N	0.2	0.2	0.5	0.5	1	0.064	Very high (1515–1894)	0.2	0.2	0.33	1	1
CI=0.013; CR=0.012							CI=0.013; CR=0.012					
Elevation (m)	Very low	Low	Moderate	High	Very high	Rating	Geology	Holocene	Pleistocene	Rating		
Very low (16–21)	1	1	0.2	0.25	0.5	0.078	New alluvial	1	5	0.833		
Low (21–26)	1	1	0.25	0.33	2	0.116	Old alluvial	0.2	1	0.167		
Moderate (26–31)	5	4	1	1	4	0.38	CI=0.00; CR=0.00					
High (31–36)	4	3	1	1	3	0.324						
Very high (36–41)	2	0.5	0.25	0.33	1	0.102						
CI=0.038; CR=0.033												

Table 7 (continued)

Slope (degree)	Very low	Low	Moderate	High	Very high	Rating	Distance from river (m)	Very low	Low	Moderate	High	Very high	Loamy soil (moderate)	Loamy soil	Rating
Rainfall (mm)	Very low	Low	Moderate	High	Very high	Rating	Soil texture	Clayey soil	Sandy soil	Coarse frag-ments	Loamy soil	Loamy soil	Loamy soil (moderate)	Loamy soil	Rating
Very low (1500–1550)	1	0.5	0.5	0.2	0.2	0.06	Clayey soil	1	5	5	1	5	5	0.38	
Low (1550–1600)	2	1	0.5	0.2	0.2	0.09	Sandy soil	0.2	1	2	0.2	0.5	0.5	0.08	
Moderate (1600–1650)	2	2	1	0.5	0.5	0.16	Coarse Frag-ments	0.2	0.5	1	0.2	0.33	0.06		
High (1650–1700)	5	5	2	1	2	0.39	Loamy soil	1	5	5	1	4	0.36		
Very high (1700–1750)	5	5	2	0.5	1	0.3	Loamy Soil (moderate)	0.2	2	3	0.25	1	0.12		
CI=0.031; CR=0.029							CI=0.054; CR=0.049								
Temperature (°C)	Very low	Low	Moderate	High	Very high	Rating	Bulk Density (g/cm ³)	Very low	Low	Moderate	High	Very high	Very high	Rating	
Very Low (20–22)	1	0.5	0.25	0.2	0.5	0.07	Very Low (1.44–1.52)	1	1	4	5	5	5	0.38	
Low (22–24)	2	1	0.25	0.2	0.5	0.09	Low (1.52–1.54)	1	1	3	5	5	5	0.36	
Moderate (24–26)	4	4	1	1	1	0.27	Moderate (1.54–1.56)	0.25	0.33	1	2	2	2	0.12	
High (26–28)	5	5	2	1	1	0.35	High (1.56–1.58)	0.2	0.2	0.5	1	2	2	0.08	
Very high (28–30)	2	2	1	1	1	0.21	Very high (1.58–1.61)	0.2	0.2	0.5	0.5	1	1	0.06	
CI=0.069; CR=0.061							CI=0.007; CR=0.006								
LULC	Agriculture	Vegetation	Water bodies	Settlement	Sand deposition	Rating	Soil CEC (cmolc/kg)	Very low	Low	Moderate	High	Very high	Very high	Rating	
Agriculture	1	2	1	5	5	0.349	Very low (11–14)	1	1	0.5	0.2	0.2	0.2	0.071	
Vegetation	0.5	1	1	5	4	0.255	Low (14–16)	1	1	0.5	0.25	0.2	0.2	0.074	
Water bodies	1	1	1	4	3	0.263	Moderate (16–18)	2	2	1	0.5	0.25	0.25	0.137	
Urban area	0.2	0.2	0.25	1	1	0.064	High (18–22)	5	4	2	1	1	1	0.326	
sand deposition	0.2	0.25	0.33	1	1	0.07	Very high (22–28)	5	5	4	1	1	1	0.392	

Table 7 (continued)

Slope (degree)	Very low	Low	Moderate	High	Very high	Rating	Distance from river (m)	Very low	Low	Moderate	High	Very high	Rating
CI=0.018; CR=0.016							CI=0.009; CR=0.008						
Soil moisture	Very low	Low	Moderate	High	Very high	Rating	Soil pH	Very Low	Low	Moderate	High	Very high	Rating
Very low (-0.320--0.134)	1	1	0.33	0.25	0.2	0.07	Very Low (5.7-5.9)	1	1	0.5	0.2	1	0.11
Low (-0.134--0.065)	1	1	0.5	0.25	0.25	0.08	Low (5.9-6.1)	1	1	0.5	0.25	0.5	0.1
Moderate (-0.064-0.014)	3	2	1	0.5	0.33	0.16	Moderate (6.1-6.3)	2	2	1	0.25	1	0.17
High (0.014-0.114)	4	4	2	1	1	0.32	High (6.3-6.5)	5	4	4	1	1	0.41
Very high (0.114-0.306)	5	5	3	1	1	0.37	Very high (6.5-6.8)	1	2	1	1	1	0.21
CI=0.023; CR=0.021							CI=0.074; CR=0.067						
MSAVI	Very low	Low	Moderate	High	Very high	Rating	Organic Carbon	Very low	Low	Moderate	High	Very high	Rating
Very low (-0.23-0.14)	1	0.5	0.33	0.25	0.2	0.06	Very low (0-2)	1	0.5	0.33	0.25	0.2	0.06
Low (0.14-0.24)	2	1	0.5	0.25	0.2	0.086	Low (2-5)	2	1	0.33	0.25	0.2	0.08
Moderate (0.24-0.32)	3	2	1	0.33	0.25	0.135	Moderate (5-8)	3	3	1	0.33	0.25	0.15
High (0.32-0.40)	4	4	3	1	0.5	0.284	High (8-12)	4	4	3	1	1	0.32
Very high (0.40-0.61)	5	5	4	2	1	0.435	Very high (12-18)	5	5	4	1	1	0.37
CI=0.033; CR=0.029							CI=0.048; CR=0.043						

Table 8 Spatial distribution of the soil suitability classes

Soil suitability classes	Area (per cent)	Area (sq.km)
Very low	12.3	25.83
Low	26.6	55.87
Moderate	31.56	66.27
High	22.93	48.16
Very high suitable	6.61	13.87

‘Rainfall’ and ‘Temperature’ parameters are also being foremost factors in land suitability analysis of any region. The spatial distribution of the average yearly (2019) rainfall was varying from 1500 to 1750 mm. The spatial distribution of rainfall has been classified into five classes as Very low (1500–1550 mm), Low rainfall zone (1550–1600 mm), Moderate rainfall zone (1600–1650 mm), High rainfall zone (1650–1700 mm) and Very High rainfall zone (1700–1750 mm) (Table 8, Fig. 4d). The temperature is considered to be one of the major parameters of plant growth. The temperature map has also been classified into five classes as Very low (20 °C–22 °C) with 19.00 per cent (39.9 sq.km), Low (22 °C–24 °C) with 66.31 per cent (139.26 sq.km), Moderate (24 °C–26 °C) with 12.77 per cent (26.82 sq.km), High (26 °C–28 °C) with 1.71 per cent (3.59 sq.km) and Very High (28 °C–30 °C) with 0.20 per cent (0.43 sq.km) of the total area. The ‘High-temperature zone’ is the most suitable zone for agriculture with the criteria value 35 per cent and the ‘Very low-temperature zone’ (Table 8, Fig. 4e) is least suitable for agriculture. Criteria Weight of both rainfall and temperature has been computed using AHP on MS Excel. Distance from the river indicates the easy availability of irrigation water. LULC map of the study area is classified into six categories (Fig. 4f). The normalized difference water index (NDWI) is promoted by Gao in 1996 (Zhang and Chen 2015) and its modified version is known as MNDWI. This index is excellent enough to acquire the information about soil moisture of any region. MNDWI is a reliable method to separate the dry land from water bodies by mapping. The values of MNDWI range from -1 to $+1$, where the higher values indicate the higher content of water (blue) and vice-versa. The spatial distribution of soil moisture (Fig. 3g) within the study area has been classified as Very low moisture zone (2.50 per cent), Low moisture zone (34.21 per cent), Moderate moisture Zone (37.73 per cent), High moisture zone (18.93 per cent), and Very high moisture zone (6.63 per cent), respectively. The spatial distribution of ‘MSAVI’ (Modified Soil Adjusted Index) has been classified as five classes; Very low MSAVI zone (-0.23 – 0.14), Low MSAVI zone (0.14 – 0.24), Moderate MSAVI zone (0.24 – 0.32), High MSAVI zone (0.32 – 0.40) and Very high MSAVI zone (0.40 – 0.61). The value of MSAVI ranges from -1 to $+1$, where pixel value 0 – 1 taken as a vegetation value

and less than or equal to 0 taken as a non-vegetation pixel (Laosuwan and Uttarak 2014; Jiang 2007). About 79.92 per cent (153.17sq.km) of the total area comes under ‘Moderate to Very high’ MSAVI zone (0.24 – 0.61) which is suitable for agriculture (Fig. 3h). Agricultural land near to the rivers having more alluvial soil and it is facilitating sufficient irrigation water (Fig. 4i) for seasonal crops. Figure 3j is showing the distance from the roads to suitable zones. More road networks indicate develop regions and the farmers can easily import high yielding seeds, machinery and can easily export their crops. Soil texture is the base of plant growth and one of the major parameters for land suitability analysis. The spatial distribution of soil texture has been classified into five classes such as coarse fragments (0.25 per cent), sandy soil (coarse texture) (4.62 per cent), clayey soil (fine texture) (39.71 per cent), loamy soil (moderately fine texture) (42.77 per cent), and loamy soil (medium texture) (12.64 per cent). The criteria values of each alternative have been calculated with the help of the AHP method. The region belongs to a very fertile soil zone (Fig. 4l), where 95.12 per cent (199.75 sq.km) of the total area is facilitated with loamy to clayey soil. Clay soils can hold nutrients very well. Bulk density is the ratio between the dry weight of the soil and its total volume. High bulk density leads to low porosity characteristics of the soil which is reduced the water filtration intensity from topsoil to deep soil horizons. High bulk density has an adverse effect on agriculture. Bulk density can be modified with apply of ‘organic matter’. The spatial distribution of bulk density of the study area has been classified as Very low BD zone (26.65 per cent), Low BD zone (45.08 per cent), Moderate BD zone (24.87 per cent), High BD zone (2.56 per cent), and Very High BD zone (0.84 per cent) of the total area, respectively (Fig. 4m). Bulk density zone ‘Moderate to Very Low’ (1.52 – 1.58) is most suitable for agriculture with an area of 96.6 per cent (202.86 sq.km) of the total area. Bulk density of soil is a very important indicator of soil compaction and health of the soil of specific soil texture (USDA, NRCS) (Table 9). ‘Cation Exchange Capacity’ (CEC) influences the nutrients holding capability of the soil and also affects the frequency of nitrogen (N_2) and Potassium fertilizer applications, the soil types, the pH of the soil, and Soil Organic carbon, etc. Nitrogen (N_2^+), Ammonium (NH_4^+), Potassium (K^+), Sodium (Na^+), Hydrogen (H^+), etc. are the most common soil cations. The spatial distribution of the CEC (cmolc/kg) of the study area has been classified into five classes (Table 8) as Very low CEC zone (11–14), Low CEC zone (14–16), Moderate CEC zone (16–18), High CEC zone (18–22), Very CEC zone (22–28), respectively. Low CEC zone (Fig. 4n) is the dominant zone concerning area with 45.08 per cent (94.67 sq.km), whereas only 28.27 per cent (59.37 sq.km) area is most suitable for agriculture (Fig. 4n, Table 8). pH value of the soil indicates its ‘acidity’ or ‘alkalinity’. The optimum pH value of the soil ranges

Table 9 Normalized pair-wise comparison matrix with criteria rating, WSV, CI and CR of the study area

Sl no	Parameters	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Rating	WSV
1	Rainfall (mm)	1	2	2	2	2	2	2	2	2	2	0.5	0.5	3	1	1	0.33	0.076	1.338
2	Temperature (°C)	0.5	1	0.33	0.5	0.5	1	1	0.5	0.5	2	0.33	0.33	1	1	1	0.33	0.035	0.596
3	Soil texture	0.5	3	1	0.5	1	1	1	3	2	2	0.33	0.33	3	2	2	0.33	0.066	1.149
4	Soil pH	0.5	2	2	1	2	2	2	2	1	2	0.33	0.33	1	1	1	0.33	0.06	1.056
5	Organic carbon (g/kg)	0.5	2	1	0.5	1	2	2	0.5	2	2	0.33	0.33	1	1	1	0.33	0.051	0.873
6	soil CEC(cmolc/kg)	0.5	1	1	0.5	0.5	1	1	2	2	1	0.33	0.33	1	1	1	0.33	0.045	0.794
7	bulk Density(g/cm ³)	0.5	1	1	0.5	0.5	1	1	0.5	0.5	2	0.33	0.33	1	1	1	0.33	0.037	0.64
8	slope (degree)	0.5	2	0.33	0.5	2	0.5	2	1	2	2	0.33	0.33	2	2	2	2	0.064	1.135
9	Elevation (m)	0.5	2	0.5	1	0.5	0.5	2	0.5	1	2	0.5	0.5	2	2	2	2	0.06	1.05
10	Aspects	0.5	0.5	0.5	0.5	0.5	1	0.5	0.5	0.5	1	0.33	0.33	0.5	0.5	2	0.5	0.032	0.554
11	Distance from river(m)	2	3	3	3	3	3	3	3	2	3	1	1	2	3	3	3	0.13	2.32
12	Distance from road(m)	2	3	3	3	3	3	3	3	2	3	1	1	2	2	2	2	0.12	2.138
13	Geology	0.33	1	0.33	1	1	1	1	0.5	0.5	2	0.5	0.5	1	1	1	0.5	0.041	0.698
14	MNDWI	1	1	0.5	1	1	1	1	0.5	0.5	2	0.33	0.5	1	1	1	0.33	0.042	0.721
15	MSAVI	1	1	0.5	1	1	1	1	0.5	0.5	0.5	0.33	0.5	1	1	1	0.33	0.039	0.673
16	LULC	3	3	3	3	3	3	3	0.5	0.5	2	0.33	0.5	2	3	3	1	0.101	1.765

from 5 to 7 for agriculture and plant growth. The pH of the soil of the study area ranges from 5.7 to 6.8 (Fig. 4o) which is good for crop production. Soil organic carbon (SOC) is an essential factor that determines the fertility of the soil. The water holding capacity and process of infiltration of rainwater vastly determine by SOC of the soil. The spatial distribution of SOC (Fig. 4p) of the study area has been categorized into five classes (Table 8) as Very low (0–2), Low (2–5), Moderate (5–8), High (8–12), and Very High (12–18), respectively. High and Very high SOC zone is better for crop production.

Soil suitability analysis

Before constructing the final agricultural land suitability map, it is necessary to prepare a soil suitability map for accruing precise knowledge about the soil characteristic of the study region. For generating the soil suitability map (Fig. 5), simple overlay mapping was performed using six soil-related parameters such as ‘Soil Texture’, ‘Soil CEC’, ‘Soil Organic Carbon’, ‘Soil pH’, ‘Soil Bulk Density’ and ‘Soil Moisture’. The output layer (Table 9) has been classified into Very low (12.30 per cent), Low suitable zone (26.60 per cent), Moderate suitable zone (31.56 per cent), High suitable zone (22.93 per cent), and Very high suitable zone (6.61 per cent).

Agriculture suitability zone (ASZ)

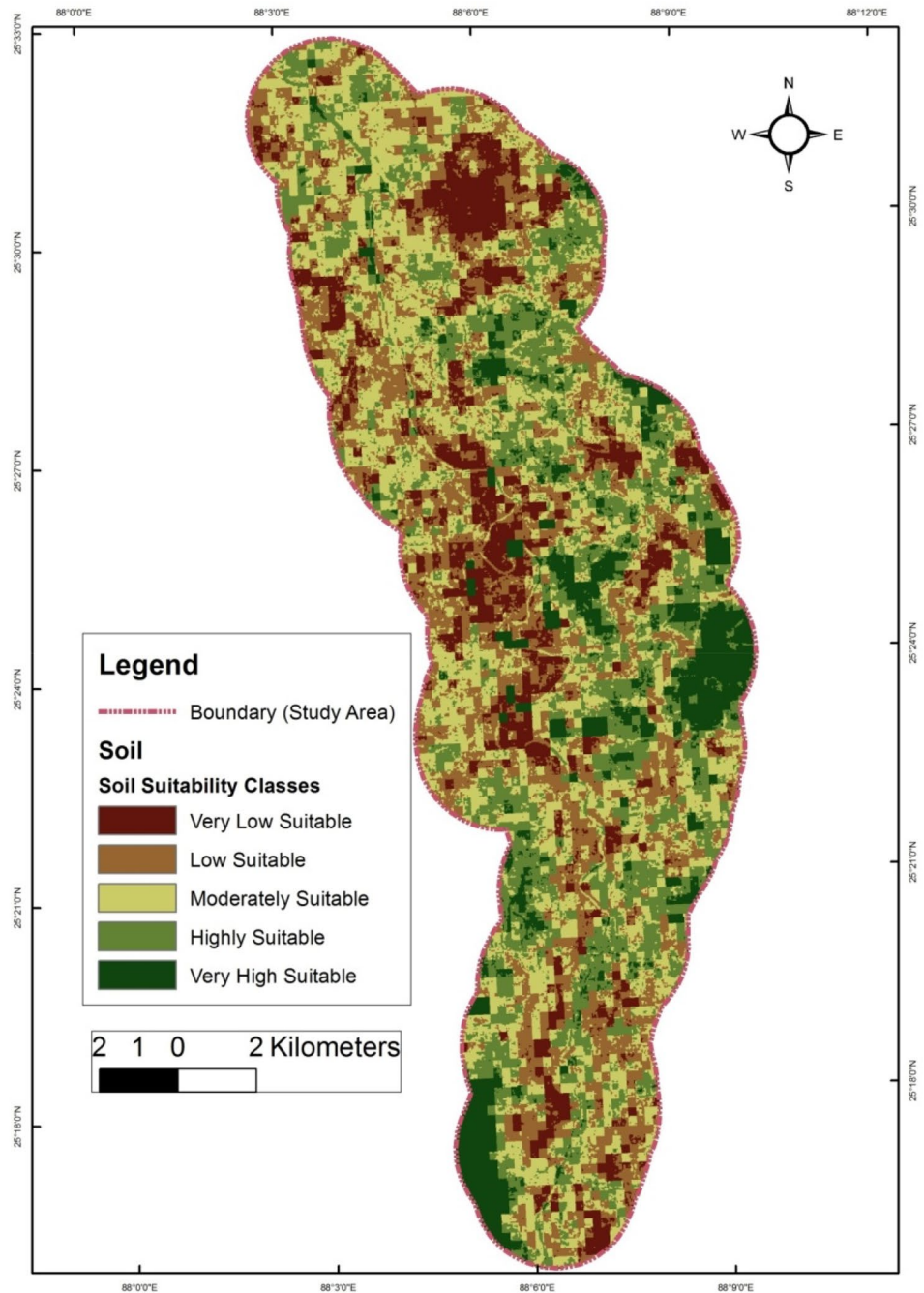
The final agricultural land suitability map is classified into five suitable classes on ArcMap-10.5, where a higher value indicates the higher suitability and the lower value indicates

the least suitability or unsuitability for agriculture. From the final ASZ map, it is determined that only 4.11 per cent area is very highly suitable, 28.65 per cent area is highly suitable and 49.67 per cent is moderately suitable for agriculture of the total area, respectively. Only 3.24 per cent of the total area is unsuitable for agriculture and 14.33 per cent area is low suitable for agriculture (Fig. 6, Table 10).

Conclusion

Land suitability analysis involves several parameters, which are in different scales ranging from nominal to ratio. In this present study, the GIS-based multi-criteria decision making technique was applied to evaluate the agricultural suitability of the study area. AHP method was used as a tool to assign the relative importance of the sixteen different criteria in this site suitability analysis. ‘GIS’ technique has been used to ‘Obtaining the result’, ‘Investigating the result’, ‘Analysing the data’ as it is a time-efficient technique. GIS-based land suitability analysis represents the continuous, complex, and uncertain information in a simple, categorized map format. Sixteen different criteria were selected to evaluate the land suitability using the GIS-based MCDM technique. The output of the research concluded that the area is an optimum region for agriculture. Only 3.24 per cent area is ‘unsuitable’ and 14.33 per cent area has ‘low suitability’ for agriculture concerning the total area, respectively. Moderate-to-high content organic carbon, low bulk density, optimum pH and cation exchange capacity of the soil, nearly flat slope, nearness of rivers and developed transportation are the major reasons

Fig. 5 Soil suitability map of the study area



behind the high potentiality, whereas the sluggish quality of soil, lack in soil moisture, low porosity with high elevation, etc. are the main causes of less productive area. Though this region is highly fertile in nature, there is also a potential chance to crop destruction during the rainy season due to flooding. For minimizing the damages and for the development of this area governmental authorities should take initiatives to improve flood forecasting

systems, flood management initiatives, develop marketing facilities, transportation, and soil management. This work will help the governmental and non-governmental agencies for implementing developmental policies and managing agricultural land in this region. This research proves that the evaluation of land suitability using GIS and AHP could be a good decision to assist this integration.

Fig. 6 Agriculture suitability zone of the study area

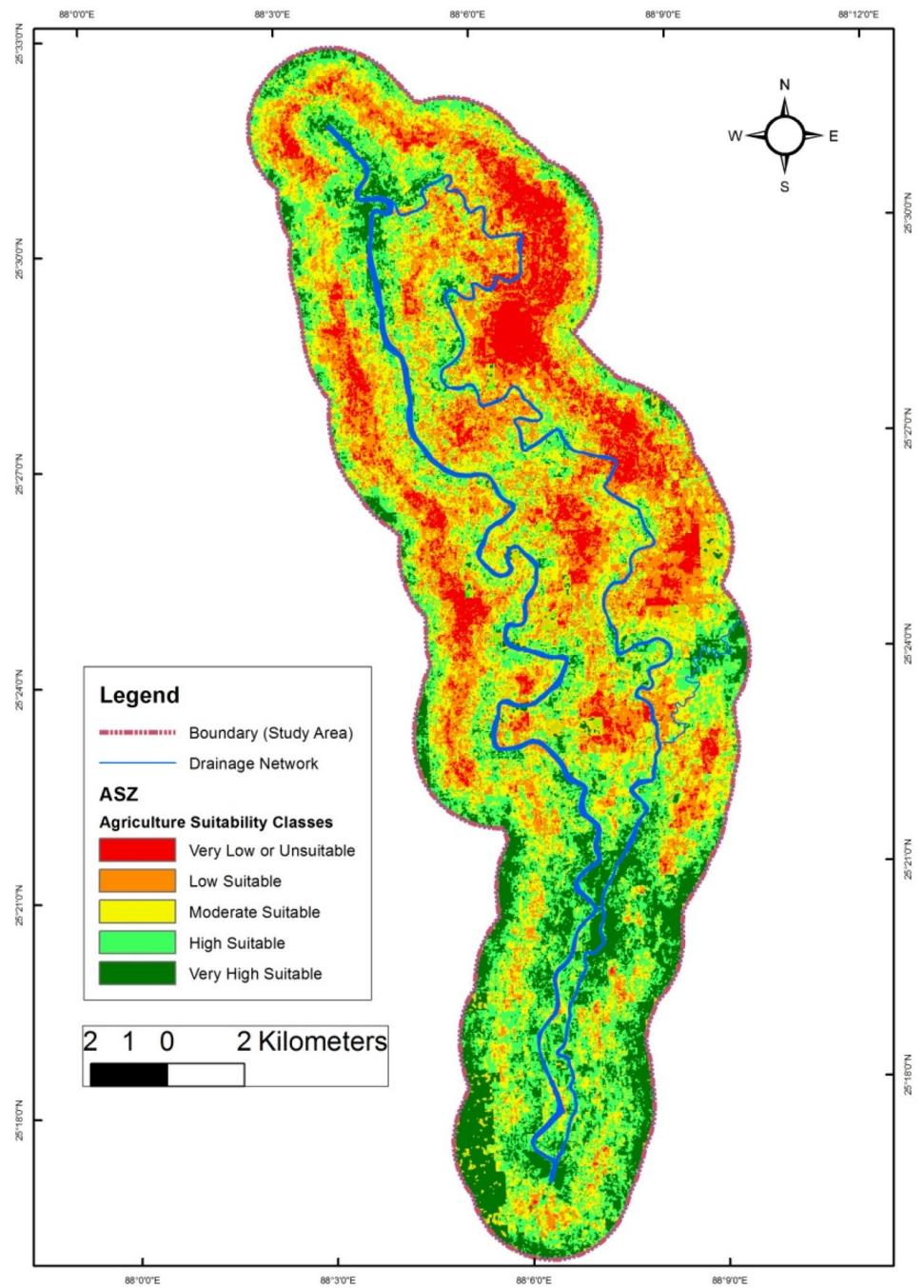


Table 10 Agriculture suitability zone of the study area

ASZ(agriculture suitability zone)	Very low suitability or unsuitable	Low suitability	Moderate suitability	High suitability	Very high suitability
Area (per cent)	3.24	14.33	49.67	28.65	4.11
Area (sq.km)	6.80	30.09	104.31	60.17	8.63

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Compliance with ethical standards

Conflict of interest The authors hereby declare that there is no conflict of interest and no human or animal involved or harmed in any way during this research work.

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