Chapter

Multi-Criteria Land Suitability Analysis for Agriculture Using AHP and Remote Sensing Data of Northern Region India

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Abstract

The purpose of this study was to identify adequate agricultural sites in Punjab's Northern region India district (India). This research employed the "Analytic Hierarchy Process (AHP)" approach, which is extensively used in land use appropriateness studies. Great soil type, land use, land cover, soil moisture, slope, aspect, elevation, drainage, geology, and geomorphology were all incorporated into the application. The ranks of influencing criteria were calculated using expert judgments and correlation analysis, while the weights were determined using a pairwise comparison matrix. The scores for sub-parameters with internal variations in the criteria assigned based on field work and published norms. The study area is considered to be highly appropriate for agricultural production in 41.2% (39044.28 ha), moderately suitable in 14.3% (13498.76 ha), and marginally suitable in 4.2% (3993 ha). Furthermore, it was discovered that 1.9% of the land is now unfit for agricultural production (1766.6 ha), while 38.4% of the area is permanently unsuitable (36372.6 ha). The following facts were also discovered to be important in achieving these results: a large portion (approximately 45%) of the study area is covered with forests, built-up areas, and water bodies, the soil depth is insufficient for agricultural production, the slope in the study area is quite steep, and thus the erosion degree is high.

Keywords: land suitability, AHP, FAO, northern region India, multi-criteria decision analysis, pairwise comparison matrix

1. Introduction

Agriculture, being man's most fundamental profession, has benefitted immensely from technological advancements ranging from shifting cultivation to high precision farming. With the advent of civilization, man learned about additional crops and began to produce a variety of crops. As the human population grew and civilization progressed, people began to dwell in one location and farm the same land year after year. Now that agriculture has evolved into a profession, it is known as commercial agriculture, with precision agriculture and sustainable agriculture as key components.

The world's population is rapidly increasing these days. To meet the rising demand for food, the agricultural community must produce more and more. Because it is difficult to bring additional land under cultivation (extensive farming) in the current scenario, when land is a limited issue, the agricultural community should take on the task of producing more and more food with the land that is available (intensive farming). On the contrary, growing worldwide concern for human health and the environment opposes the use of higher levels of pesticides and fertilizers, as well as genetically modified plants. The latter, on the other hand, are present technologies that have the potential to improve food production.

Crop needs and soil/land conditions influence adaptability. Suitability is determined by matching the land features to the crop needs. Suitability is a measure of whether a land unit's features meet the needs of a certain type of land use (FAO). Aside from land and soil qualities, additional driving elements that might impact crop choices include socioeconomic, market, and infrastructural factors.

The FAO Land Evaluation Framework is based on previous land capabilities methodologies. In this case, the overall land appropriateness of a land area for a particular land use is assessed using a series of more or less independent land attributes, each of which may limit the land-use potential. These assessments are frequently used to classify map units in natural resource inventories. A soil survey's legend categories are divided into suitability subclasses based on the quantity and severity of land use restrictions.

In the FAO framework, there are two sorts of categories based on the scale of measurement of appropriateness.

- Qualitative: in reconnaissance investigations, the classes are rated based on the physical production potential of the land. It is employed to assess environmental, social, and economic factors.

- Quantitative: the classes are specified in numerical terms that allow for comparison of the objectives. There are a lot of economic parameters employed here.

By introducing quantification of land suitability indicators over a whole area, quantified land evaluation [1] revolutionized land suitability evaluation. The area is divided into small grid cells, and cell-based modeling has started. The indicators, on the other hand, must be quantitative. Geographical information systems and geostatistical approaches are commonly used in such land suitability analyses.

The FAO Framework identifies four categories of increasing details, as shown in **Table 1**.

Land appropriateness is a factor in determining a land use's long-term viability. The sustainability of a land use is defined by its suitability and vulnerability. Maximum appropriateness and minimum vulnerability should be the goals of sustainable land use (**Figure 1**) [2].

According to Rossiter [3], land is distinctive in every location, and this uniqueness has an impact on land usage. He also mentions how land evaluation might help with agricultural support services.

The multi-criteria land suitability was evaluated in a non-spatial manner, assuming spatial homogeneity across the study region. However, in circumstances like land

S. No.	Categories	Explanation
1	Land Suitability Orders	Reflecting kinds of suitability
2	Land Suitability Classes	Reflecting degrees of suitability within Orders
3	Land Suitability Subclasses	Reflecting kinds of limitation, or main kinds of improvement measures required, within Classes
4	Land Suitability Units	Reflecting minor differences in required management

Table 1.
FAO structure of land suitability classification.

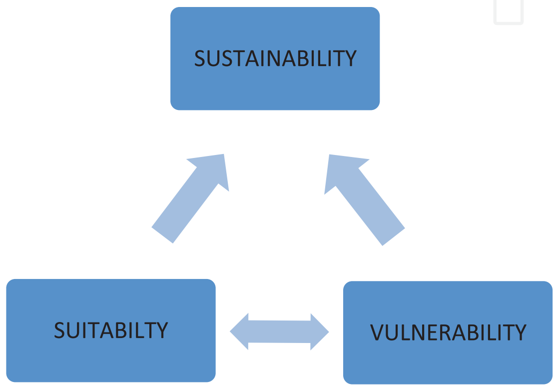

Figure 1.
Land use sustainability (after [2]).

suitability studies, when decisions are made based on factors that change over space, this is impossible [4]. Non-spatial traditional MCDM techniques average or total the effects that are judged appropriate for the entire area under consideration to address the spatial decision [5]. Jankowski [6] suggests that making, MCE, and GIS can all be combined. For many crops, MCE appears to be applicable in GIS-based land suitability analyses [7].

Ranking and rating are two widely used MCE approaches in land suitability evaluations. These methods lack a theoretical underpinning in determining the weights. The weights are assigned quite haphazardly in these procedures. They do not take into account comparisons between criteria and classifications. Furthermore, the results of such an investigation are grouped together using a simple Boolean overlay or weighted aggregation.

Since its beginnings, several researchers have examined the Analytic Hierarchy Process (AHP) [8]. The Analytic Hierarchy Process (AHP) is a method for making multi-criteria decisions (MCDM). The earliest reference we have identified is from 1972 [9]. The method was then discussed in detail in a paper published in the Journal of Mathematical Psychology [10]. The vast majority of applications continue to use AHP in the manner specified in this first article, oblivious to subsequent developments. This study draws out the significant trends in methodological advancements and future research in this vital topic.

AHP has been widely used since its introduction, for example, in flexible manufacturing system [11], Machine selection [12], industrial R&D project selection and resource allocation [13], Delphi method [14], Computer-aided machine-tool selection [15], evaluating machine tool alternatives [16], Integrating fuzzy theory and hierarchy concepts to evaluate software quality [17], product design in concurrent engineering [18]. Issue resolution for conceptual design using AHP [19]. Selection of appropriate schedule delay analysis method [20].

2. Study area and data used

2.1 Study area

Northern region India is a city in India's Punjab state. On July 27, 2011, Northern region India was formally designated as a district of Punjab state (Previously it was a Tehsil of Gurdaspur district, Punjab). Northern region India district is located in Punjab's northernmost region (**Figure 2**).

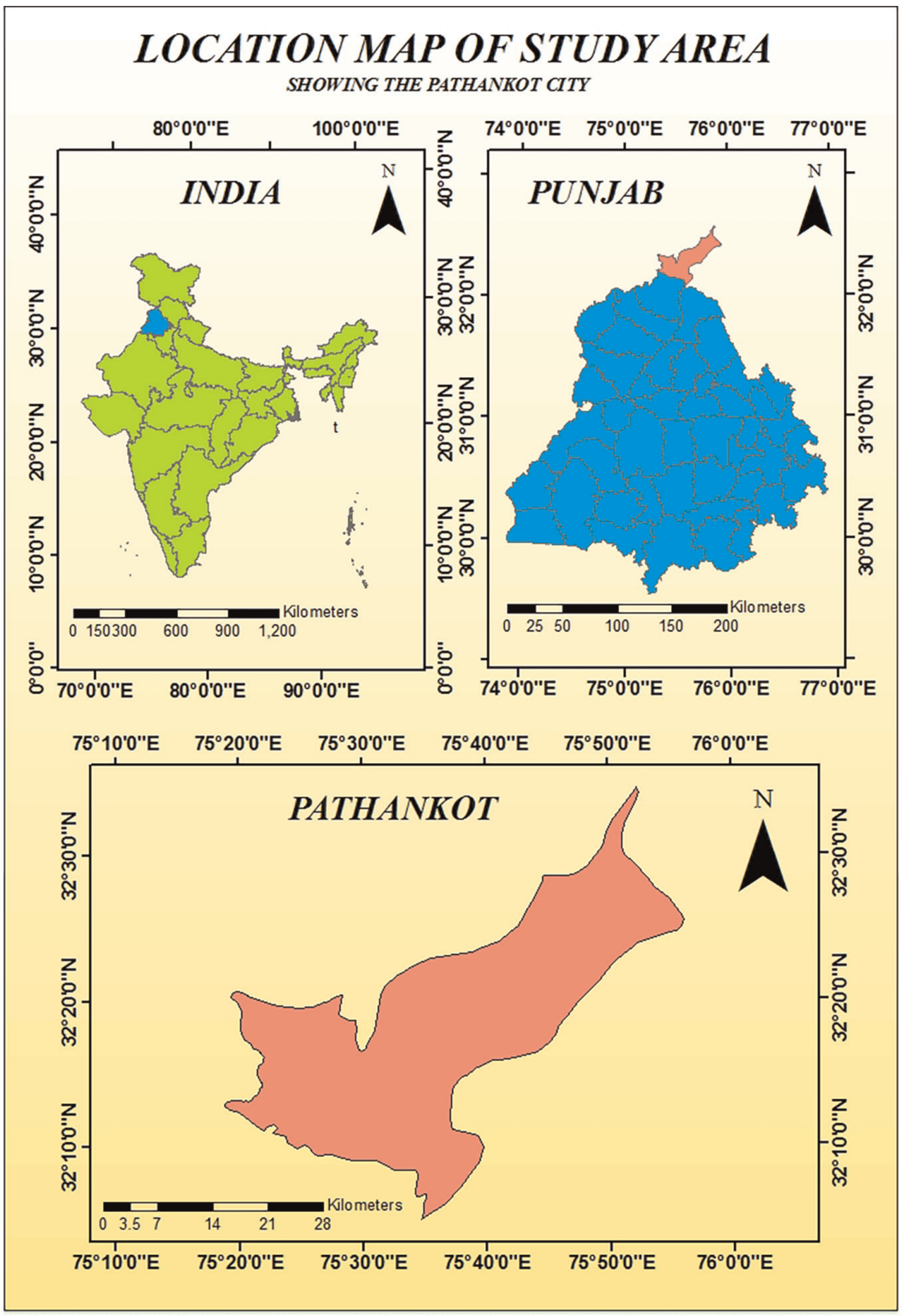

Figure 2.
Location of the study area.

It is where the three northern states of Punjab, Himachal Pradesh, and Jammu and Kashmir come together. Northern region India serves as a transportation hub for the three northern states due to its strategic location. It is the last city in Punjab on the national highway that connects Jammu and Kashmir to the rest of the country. Northern region India is also a major educational center for the nearby states of Jammu and Kashmir and Himachal Pradesh. It is located in the Jalandhar division, between the Ravi and the Beas rivers.

Northern region India district is located between 32°23′31″ and 32°23′52″ north latitudes and 75°39′55″ to 75°56′12″ east longitudes and covers an area of 27,123 ha. On a 1:50 K scale, the Survey of India 43 P/11, 43 P/14, and 43 P/15 top sheets cover the area.

2.2 Data used

See **Table 2**.

2.3 Data sets prepared

The shuttle radar topography mission (SRTM) elevation data (30 m resolution) obtained from USGS explorer (https://earthexplorer.usgs.gov/) was used to create a digital elevation model (DEM) of the study area. Using the DEM data slope, aspect, drainage density, Elevation thematic layers were built using ArcGIS 10.5. The land use and land cover data is downloaded by Nasa earth data ORNL DAAC (https://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=1336). Soil map was obtained from European soil data center (ESDAC) which was published by National atlas and thematic map organization, Department of science and technology (https://esdac.jrc.ec.europa.eu/content/national-atlas-india-northern-india-plate-199-soil-regions).Geology and Geomorphology data of Northern region India is downloaded from Bhukosh (http://bhukosh.gsi.gov.in/Bhukosh/MapViewer.aspx). Sentinel2 data of the study area is downloaded from Copernicus(https://scihub.copernicus.eu/). Using the Sentinel 2 data NDWI was built in ArcGIS 10.5.These resulted thematic maps: Slope, LULC, NDWI and Drainage density were integrated in ArcGIS 10.5 and finally soil suitability map was obtained (**Figures 3–11**; **Tables 3–11**).

S. No	Data set	Spatial resolution/scale	Source
1	Sentinel 2	10 m	Copernicus
2	SRTM Dem	30 m	USGS Earth Explorer
3	Land use and land cover data	100 m	NASA Earth Data ORNL DAAC
4	Soil map	1:2000000	European soil data center (ESDAC)
5	Geology	1:2000000	Bhukosh
6	Geomorphology	1:250000	Bhukosh

Table 2.
Data set and data source.

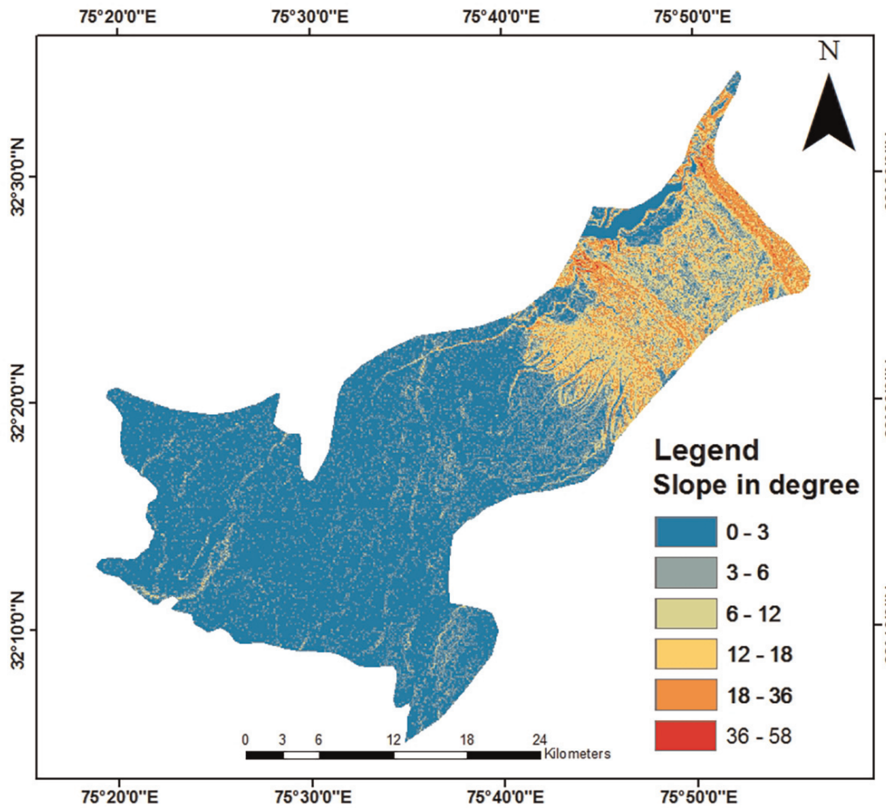

Figure 3.
Slope map.

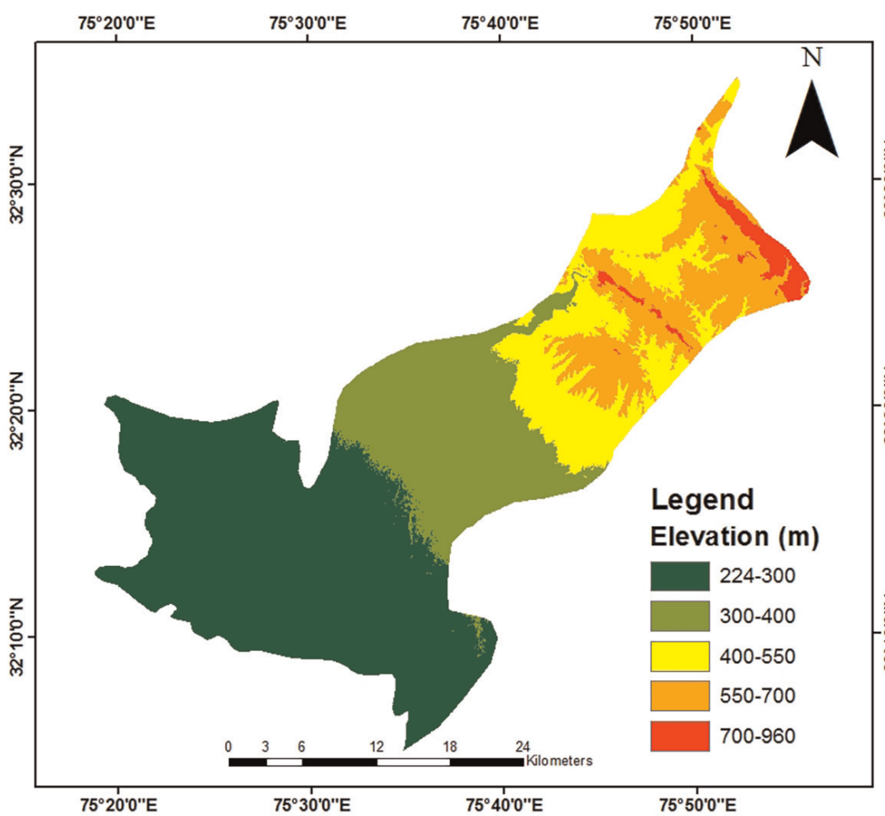

Figure 4.
Elevation map.

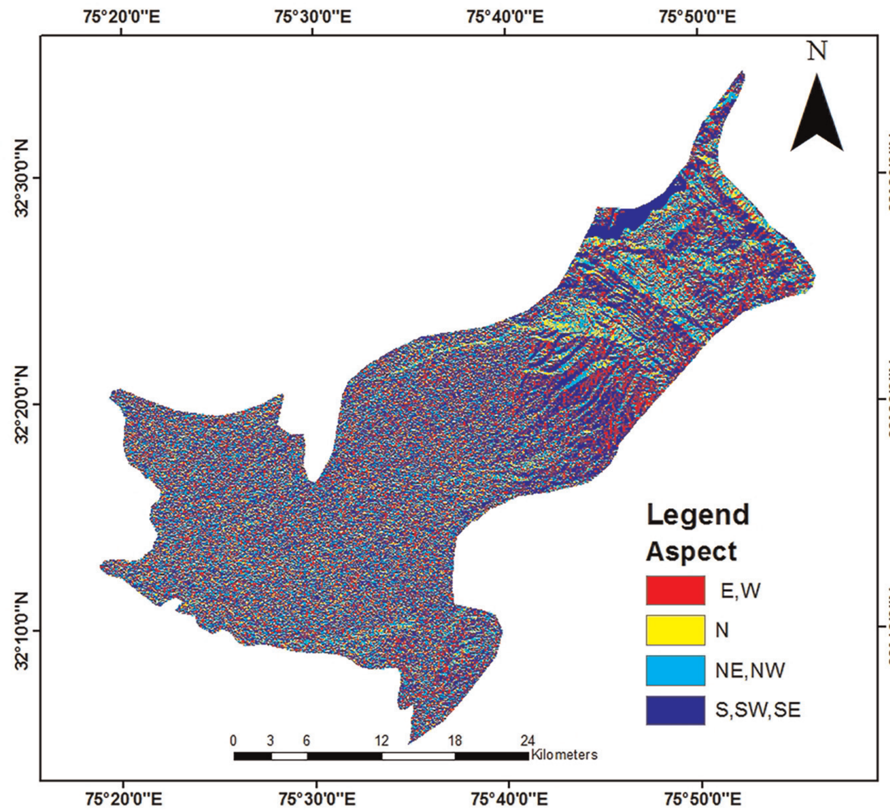

Figure 5.
Aspect map.

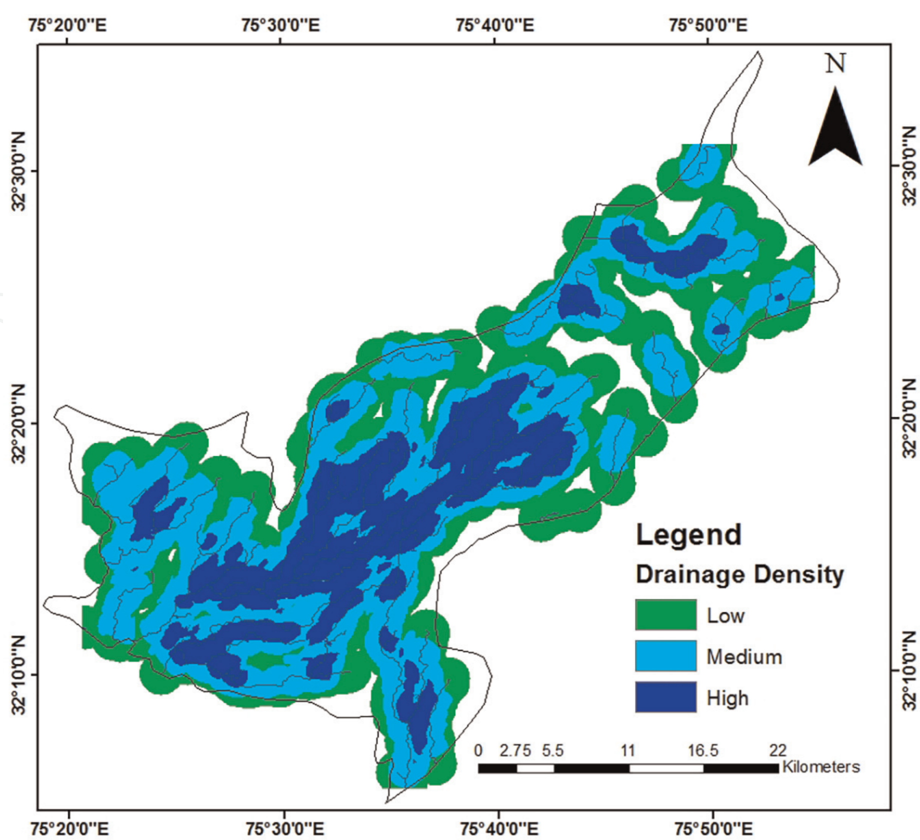

Figure 6.
Drainage map.

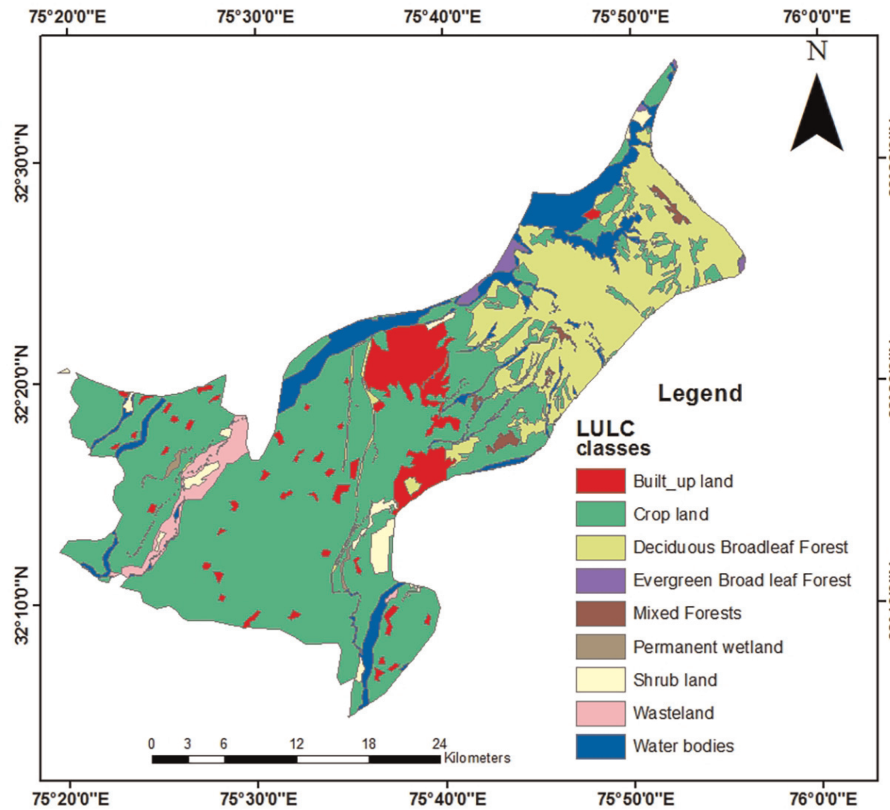

Figure 7.
Land use and land cover.

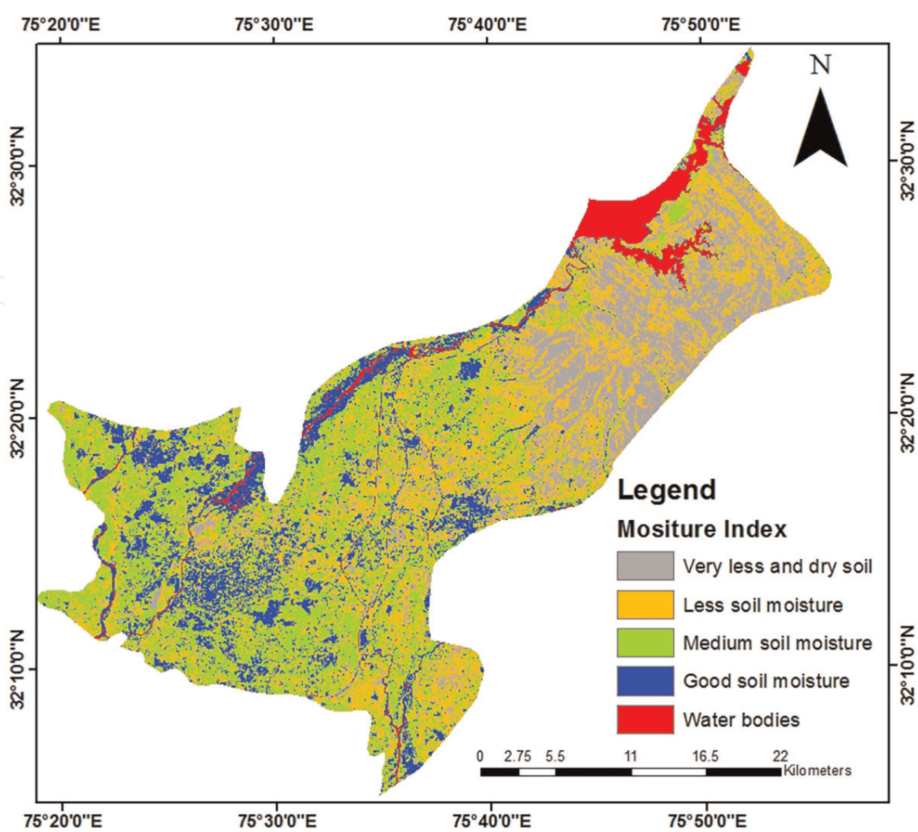

Figure 8.
Moisture index map.

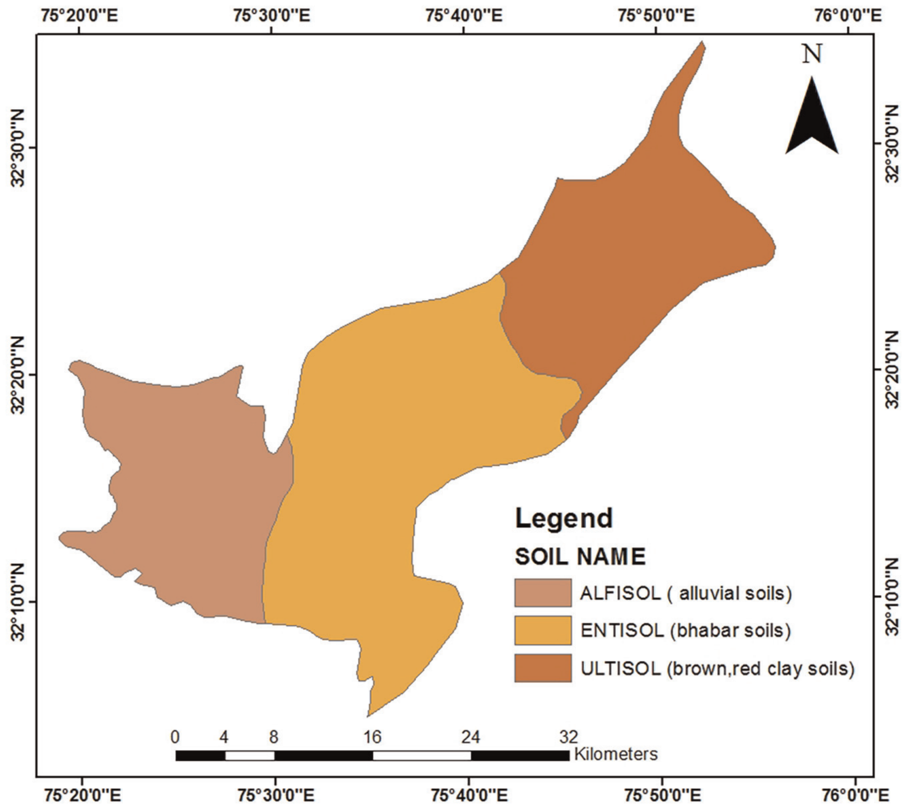

Figure 9.
Soil map.

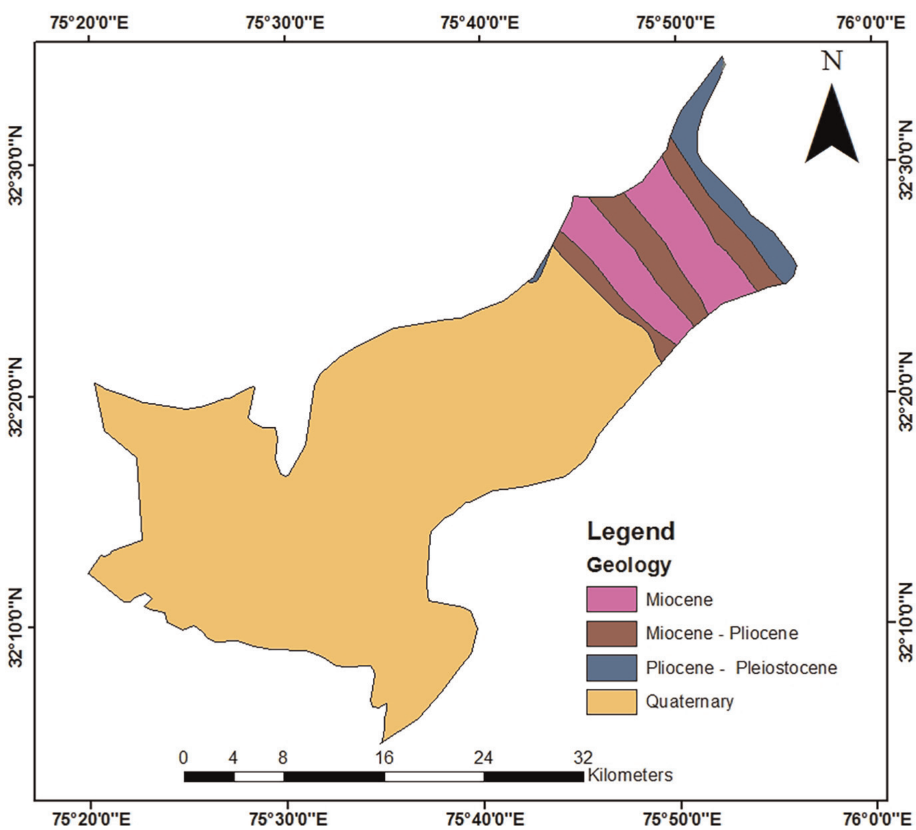

Figure 10.
Geology map.

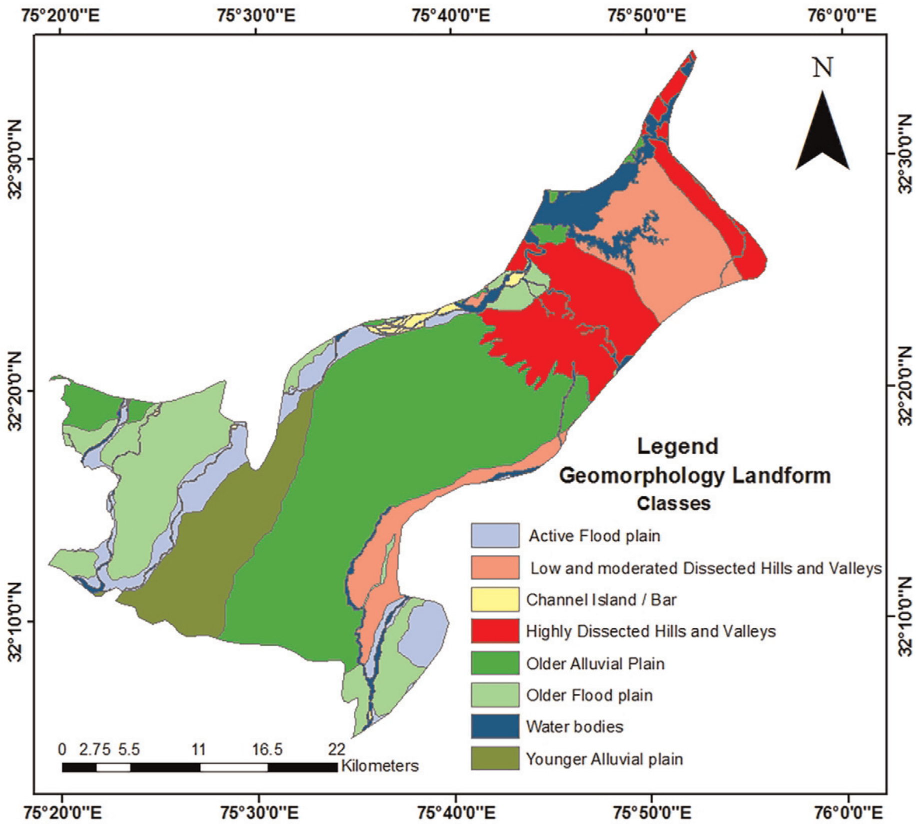

Figure 11.
Geomorphology landform map.

Slope angle (°)	Area (ha)
0–3	66049.4
3–6	13244.1
6–12	8884
12–18	6252.5
18–36	5234.1
36–58	144.8

Table 3.
Slope angle and its area coverage.

Elevation (m)	Area (ha)
224–300	46573.82
300–400	21522.16
400–550	16241.04
550–700	13350.39
700–960	2098.89

Table 4.
Elevation and its area coverage.

Aspect	Area (ha)
East, West	25205.63
North	10275.67
Northeast, Northwest	21756.82
South, Southwest, Southeast	42581.89

Table 5.
Aspect and its area coverage.

Drainage density	Area (ha)
High	24970.4
Medium	37780.1
Low	35291.3

Table 6.
Drainage density and its area coverage.

Class	Area (ha)
Water bodies	8967.44
Evergreen broad leaf forest	595.94
Crop land	57921.61
Built up area	6828.81
Deciduous broadleaf forest	19649.35
Shrub land	1749.07
Permanent wetland	210.61
Wasteland	2236.91
Mixed forest	623.53

Table 7.
LULC and its area coverage.

Moisture index	Area (ha)
Good Soil Moisture	13341.96
Medium Soil Moisture	37086.93
Less Soil Moisture	28455.66
Very Less and Dry Soil Moisture	16474.77
Water Bodies	4453.2

Table 8.
Moisture index and its area coverage.

Soil type	Area (ha)
Alfisol (alluvial soil)	25614.38
Entisol (bhabar soil)	46344.83
Ultisol (brown, red clay soil)	27851.02

Table 9.
Soil and its area coverage.

Geology type	Area (ha)
Miocene	8693.8
Miocene - Pliocene	6611.5
Pliocene - Pleiostocene	3241.69

Table 10.
Geology and its area coverage.

Geomorphology landform	Area (ha)
Active Flood plain	6612
Older Flood plain	12,852
Low and moderated Dissected Hills and Valleys	11,488
Water bodies	5848
Older Alluvial Plain	34,920
Highly Dissected Hills and Valleys	12,364
Channel Island / Bar	572
Younger Alluvial plain	9736

Table 11.
Geomorphology landform and its area coverage.

3. Methodology

Because all the selected criteria are in different units, they must be converted to the same units in order to use the Weighted Overlay Method, which necessitates the use of a standardized value. Standardization techniques transform measurements into uniform units, and the resulting score loses its dimension as well as the unit of measurement for every criterion [21]. All the criteria maps' vector layers were transformed to raster layers. After that, all raster layers were categorized and utilized as input data for the weighted overlay method, which resulted in the creation of the agricultural suitability map. The sub-criteria were ranked on a scale of one to ten, with one being the least significant and ten being the most significant.

One of the most important multicriteria decision-making strategies is the analytical hierarchy process. The procedure is used for a set of criteria or sub-criteria to create a hierarchical structure by assigning weight to each criterion [22].

Relative importance	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 judgments	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 12.
The fundamental scale for pairwise comparison matrix [25].

The analytic hierarchy process provides a structural foundation for quantifying the strong comparison of design criteria and elements in a paired technique, reducing the decision-making process's complexity [10, 23]. The weight values are determined using a pairwise comparison technique based on the relative significance of the criterion, two at a time [23]. By picking the eigenvalue corresponding to the highest eigenvector of the completed matrix and normalizing the total of the factors to unity, the analytic hierarchy method derives the weights for each individual criterion using the pairwise comparison matrix [4, 24, 25].

The pairwise comparison matrix was generated using the analytic hierarchy procedure described above, using a scale of 1–9, where 9 represents important relevance and 1 indicates equal relevance of the in between criterion of the matrix presented in (**Table 12**) [4, 24, 25].

The reciprocity criteria are mostly used in the comparison matrix, which is mathematically stated as n $(n-1)/2$ for the n number of components in a pairwise comparison matrix [25, 26]. The relative weights and eigenvectors are calculated using Saaty's technique [25] after the pairwise matrix has been computed (**Tables 14** and **15**). Furthermore, one of the major properties of the analytic hierarchy method is that it finds and calculates the inconsistencies of decision makers [24, 25, 27]. The consistency relationship (CR), which is measured by Eq. (1), is used to estimate the efficiency criteria of the analytic hierarchy method.

$$\mathrm{CR} = \mathrm{CI}/\mathrm{RI} \tag{1}$$

The CR is represented by Eq. (1), where CI stands for consistency index and RI stands for random index.

The consistency relationship aids in the determination of possible events and measures the decision maker's/judgments' logical inconsistencies [28–30]. It denotes the probability that the matrix judgments were produced at random [10, 31]. The

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 13.
Random inconsistency indices (RI) for n = 10.

Consistency Index and Random Index are the most important factors in determining the CR.

$$CI = (\lambda_{max} - n)/(n - 1) \quad (2)$$

Equation (2) represents the Consistency Index (CI), in which k max is the principle or highest eigenvector of the computed matrix and n is the matrix order.

The Random Index (RI) is the mean value of the consistency index based on the computed matrix order as demonstrated by Saaty [10] (**Table 13**). If the CR value is [0.10], the weight values in the matrix show irregularities, and the approach (AHP) may not produce relevant results [25]. The calculated CR in this investigation was 0.0669, which is within acceptable limits, and the computed weight values are accurate. The obtained weight values are then transformed to percentages in GIS for weighted overlay analysis (WOA), as shown in **Tables 14** and **15** (**Figure 12**).

4. Results and discussion

Weighted Overlay Analysis was carried out to generate the land suitability for agriculture in the Northern region India district using the weight values of selected factors derived from the Analytic Hierarchy Process and specified scores of sub-criteria (**Table 16**). Land suitability for agriculture is classified into five levels, according to the Food and Agricultural Organization (FAO): highly suitable agricultural land, moderately suitable agricultural land, marginally suitable agricultural land, land currently not suitable for agriculture, and permanently not suitable for agricultural production (**Table 17**).

High altitude (224–960 m), high slope (3–58) with higher gully erosion intensity, and less drainage availability of the study area were significant factors, resulting in a smaller area or lower rate of highly appropriate agricultural land in Northern region India (**Figure 13** and **Table 18**).

5. Conclusion

The primary goal of this research was to identify potential agricultural land in the Northern region India district. For the evaluation, an analytical hierarchy approach with a combination of geographic information systems (GIS) was used, and nine different criteria were chosen. The Analytic Hierarchy Process with GIS Integration was shown to be quite useful in determining the best agricultural site. Only 41.2% (39044.28 ha) of the study area was largely suitable for farming at the end of the evaluation, while 40.3% (38139.2 ha) was permanently and temporarily unsuitable for agricultural production. However, inefficient production problems are caused by

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

Table 14.
Pairwise comparison matrix for multi-criteria decision problems.

Criteria	Slope	Elevation	LULC	Soil moisture	Soil	Geomorphology	Drainage	Geology	Aspect	Weights
Slope	0.319	0.426	0.326	0.248	0.223	0.252	0.207	0.198	0.184	0.264
Elevation	0.159	0.213	0.326	0.248	0.223	0.209	0.207	0.173	0.163	0.214
LULC	0.159	0.106	0.163	0.330	0.278	0.168	0.177	0.173	0.163	0.190
Soil moisture	0.105	0.070	0.040	0.083	0.167	0.168	0.148	0.149	.0143	0.119
Soil	0.079	0.053	0.032	0.027	0.056	0.126	0.118	0.124	0.122	0.082
Geomorphology	0.054	0.043	0.040	0.020	0.018	0.042	0.089	0.099	0.081	0.054
Drainage	0.045	0.030	0.027	0.016	0.014	0.014	0.029	0.049	0.061	0.034
Geology	0.039	0.030	0.023	0.014	0.011	0.010	0.015	0.025	0.061	0.025
Aspect	0.035	0.027	0.020	0.012	0.009	0.010	0.009	0.008	0.020	0.018

Maximum eigenvalue (λ_{max}) = 9.79.
n = 9.
Consistency index (CI) = (λ_{max} - n)/ (n - 1) = 0.098.
Random index (RI) = 1.46.
Consistency ratio (CR) = (CI/RI) = 0.0676 $<$ 0.10.

Table 15.
Normalized pairwise comparison matrix for multi-criteria decision making.

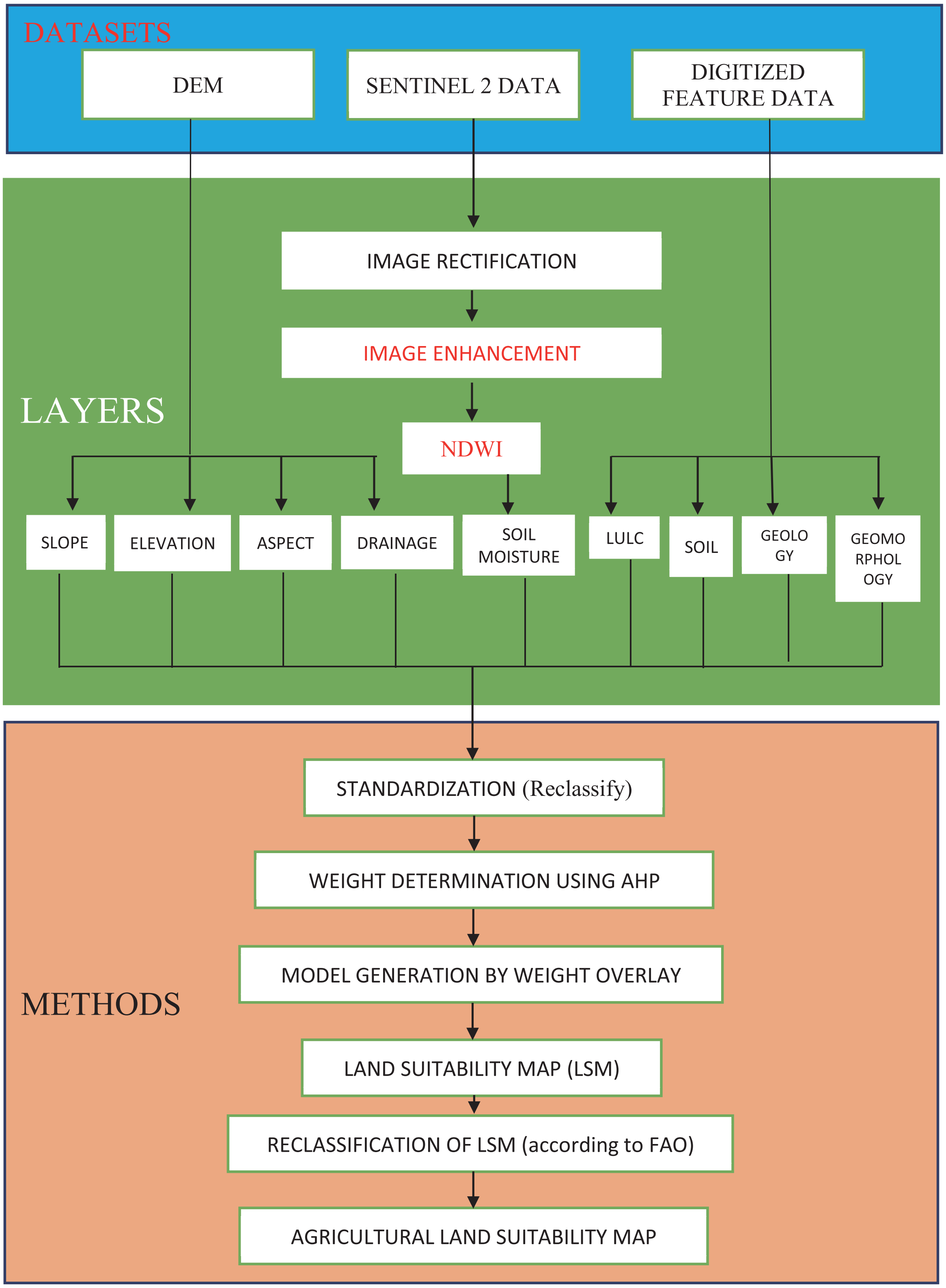

Figure 12.
Procedure followed in generating agricultural land use suitability map.

geomorphological qualities such as very high elevation, steep slope, reduced soil moisture, the presence of bare rocks, and a lack of irrigation system availability. As a result of all these concerns, a moderate quantity of land in the study district has been identified as appropriate for agricultural production. The established result can be implemented into the agricultural production decision-making process in the study

Main criteria	Weight	Influence (%)	Sub-criteria	Score
Slope	0.264	26.4	0–3	10
			3–6	8
			6–12	6
			12–18	4
			18–36	2
			36–58	1
Elevation	0.213	21.4	224–300	10
			300–400	9
			400–550	8
			550–700	7
			700–960	5
LULC	0.190	19	Crop Land	10
			Shrub Land	4
			Wasteland	3
			Evergreen Broad leaf Forest	Restricted
			Mixed Forest	Restricted
			Deciduous Broadleaf Forest	Restricted
			Built up Area	Restricted
			Permanent wetland	Restricted
			Water bodies	Restricted
Soil Moisture	0.119	11.9	Good Soil Moisture	10
			Medium Soil Moisture	7
			Less Soil Moisture	4
			Very Less and Dry Soil Moisture	1
			Water Bodies	Restricted
Soil	0.082	8.2	Alfisol (alluvial soil)	9
			Entisol (bhabar soil)	6
			Ultisol (brown, red clay soil)	3
Geomorphology	0.054	5.4	Younger Alluvial plain	10
			Older Alluvial Plain	9
			Older Flood plain	8
			Low and moderated Dissected Hills	3
			Active Flood plain	2
			Channel Island / Bar	1
			Highly Dissected Hills and Valleys	1
			Water bodies	Restricted

Main criteria	Weight	Influence (%)	Sub-criteria	Score
Drainage	0.034	3.4	High	9
			Medium	7
			Low	4
Geology	0.025	2.5	Quaternary	9
			Pliocene - Pleiostocene	7
			Miocene - Pliocene	5
			Miocene	3
Aspect	0.018	1.8	South, Southwest, Southeast	9
			East, West	5
			Northeast, Northwest	4
			North	2

Table 16.
Weights of the criteria and scores of the sub-criteria.

Suitability level	Suitable areas for agricultural production	
	Area(ha)	%
High suitability	390442.28	41.2
Moderate suitability	13498.76	14.3
Marginally suitable	3993	4.2
Currently not suitable	1766.6	1.9
Permanently not suitable	36372.6	38.4

Table 17.
Areal and percentile distribution of agricultural land suitability analysis results.

area, as it provides insight into determining suitable sites. By critically assessing the procedures and approaches used, the results can be more precise. Physical elements (topographical properties, soil and geological characteristics, etc.) are only part of the analysis, which must also include economic and social conditions for agricultural production. Because the pairwise comparison approach is based on expert judgments, which are primarily subjective in nature, it is used in the analytic hierarchy process. As a result, any incorrect judgment on any of the selected factors can be effectively communicated to the score assignment and weight designation. This is the main disadvantage of the analytic hierarchy approach; hence, weights and scores must be carefully chosen [32, 33]. For more helpful and accurate results, the study should focus on a few key species, such as several therapeutic plants and species that have substantial economic worth and also influence the advancement of rural tourism. The use of very high-resolution satellite images will aid in the assessment of finer areas.

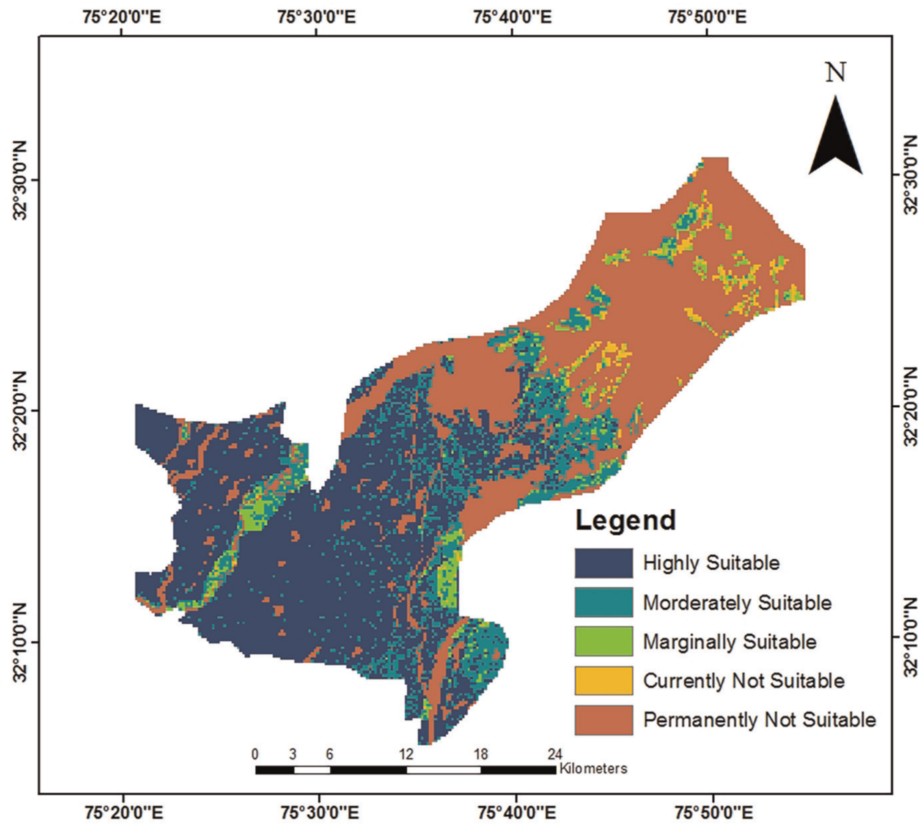

Figure 13.
Agriculture land suitability map of northern region India.

Suitability level	Suitable areas for agricultural production		Land qualities/characteristics	Remarks
	Area (ha)	%		
High suitability	390442.28	41.2	Gentle slopes (0–3) with gullies, high soil moisture with lower elevation, alluvial soil, good drainage capacity	Most suitable for agriculture, favorable area for intensive agriculture if irrigation facilities are available
Moderate suitability	13498.76	14.3	Gentle to stiff slopes (3–10) with micro terracing, medium soil moisture with lower elevation, moderate drainage capacity	Suitable land for farming practices with proper management, suitable for terrace cultivation
Marginally suitable	3993	4.2	(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
Currently and permanently not suitable	38139.2	40.3	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

Table 18.
Land suitability levels and their land characteristics.

Before the ultimate implementation, the indicated locations must also be documented on the ground with various other local and regional parameters.

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References

[1] Beek KJ, Burrough PA. Quantified Land Evaluation Procedures: Proceedings of the International Workshop. Enschede, Netherlands: International Institute for Aerospace Survey and Earth Sciences; 1987

[2] de la Rosa D. Micro LEIS 2000: Conceptual Framework. Instituto de Recursos naturales y Agrobiologia, CSIC, Avda: Sevilla, Spain; 2000

[3] Rossiter DG. A theoratical framework for land evaluation. Geoderma. 1996;**72**: 165-202

[4] Malczewski J. GIS and Multicriteria Decision Analysis. USA and Canada: John Wiley & Sons; 1999

[5] Tkach RJ, Simonovic SP. A new approach to multi-criteria decision making in water resources. Journal of Geographic Information and Decision Analysis. 1997;**1**(1):25-43

[6] Jankowski P. Integrating geographical information systems and multiple criteria decision making methods. International Journal of Geographic Information System. 1995;**3**(2):251-273

[7] Pereira JMC, Duckstein L. A multiple criteria decision-making approach to GIS- based land suitability evaluation. International Journal of Geographical Information Science. 1993; **7**(5):407-424

[8] Ishizaka A, Labib A. Review of the main developments in the analytic hierarchy process. Expert Systems with Applications. 2011;**38**(11):14336-14345

[9] Saaty T. An Eigenvalue Allocation Model for Prioritization and Planning. In Working Paper. Pennsylvania: Energy Management and Policy Center University of Pennsylvania; 1972

[10] Saaty TL. A scaling method for priorities in hierarchical structure. Journal of Mathematical Psychology. 1977;**15**:3

[11] Shang J, Sueyoshi T. A unified framework for the selection of a flexible manufacturing system. European Journal of Operational Research. 1995;**85**(2): 297-315

[12] Myint S, Tabucanon MT. A multiple-criteria approach to machine selection for flexible manufacturing systems. International Journal of Production Economics. 1994;**33**(1–3):121-131

[13] Liberatore MJ. An extension of the analytic hierarchy process for industrial R&D project selection and resource allocation. IEEE Transactions on Engineering Management. 1987;**1**:12-18

[14] Khorramshahgol R, Moustakis VS. Delphic hierarchy process (DHP): A methodology for priority setting derived from the Delphi method and analytical hierarchy process. European Journal of Operational Research. 1988;**37**(3): 347-354

[15] Duran O, Aguilo J. Computer-aided machine-tool selection based on a fuzzy-AHP approach. Expert Systems with Applications. 2008;**34**(3):1787-1794

[16] Ayağ Z, Özdemir RG. A fuzzy AHP approach to evaluating machine tool alternatives. Journal of Intelligent Manufacturing. 2006;**17**(2):179-190

[17] Chang CW, Wu CR, Lin HL. Integrating fuzzy theory and hierarchy concepts to evaluate software quality.

Software Quality Journal. 2008;**16**(2): 263-276

[18] Xu L, Li Z, Li S, Tang F. A decision support system for product design in concurrent engineering. Decision Support Systems. 2007;**42**(4): 2029-2042

[19] Lin YJ, Huang CW, Tseng JC, Shiau JY. Issue resolution for conceptual design using AHP. In: Intelligent Systems in Design and Manufacturing. Vol. 5605. Bellingham: SPIE; 2004. pp. 47-53

[20] Adhikari I, Kim SY, Lee YD. Selection of appropriate schedule delay analysis method: Analytical hierarchy process (AHP). In: Proceedings on PICMET. IEEE: Istanbul, Turkey; 2006

[21] Effat HA, Hassan OA. Designing and evaluation of three alternatives highway routes using the analytical hierarchy process and the least-cost path analysis, application in Sinai peninsula, Egypt. Egyptian Journal of Remote Sensing and Space Science. 2013;**16**(2):141-151

[22] Kiker GA, Bridges TS, Varghese A, Seager TP, Linkov I. Application of multicriteria decision analysis in environmental decision making. Integrated Environmental Assessment and Management. 2005;**2**:95-108

[23] Miller W, Collins W, Steiner FR, Cook E. An approach for greenway suitability analysis landscape and urban planning. International Journal of Geographical Information Science. 1998; **42**(2–4):91-105

[24] Feizizadeh B, Jankowski P, Blaschke T. A GIS based spatially-explicit sensitivity and uncertainty analysis approach for multi-criteria decision analysis. Computational Geosciences. 2014;**64**:81-95

[25] Thomas PG, Doherty PC. The analytic hierarchy. In: Process: Planning Priority Setting, Resource Allocation. New York: McGraw-Hill; 1980

[26] Akinci H, Ozalp AY, Turgut B. Agriculture land use suitability analysis using GIS and AHP technique. Computers and Electronics in Agriculture. 2013;**97**:71-82

[27] Garcia JL, Alvarado A, Blanco J, Jimenez E, Maldonado AA, Cortés G. Multi-attribute evaluation and selection of sites for agricultural product warehouses based on an analytic hierarchy process. Computers and Electronics in Agriculture. 2014;**100**: 60-69

[28] Cengiz T, Akbulak C. Application of analytical hierarchy process and geographic information systems in land-use suitability evaluation: A case study of Dumrek village. The International Journal of Sustainable Development & World Ecology. 2009;**16**(4):286-294

[29] Chen H, Liu G, Yang Y, Ye X, Shi Z. Comprehensive evaluation of tobacco ecological suitability of Henan Province based on GIS. Agricultural Sciences in China. 2010a;**9**(4):583-592

[30] Chen Y, Yu J, Khan S. Spatial sensitivity analysis of multi-criteria weights in GIS-based land suitability evaluation. Environmental Modelling & Software. 2010;**25**(12):1582-1591

[31] Park S, Jeon S, Kim S, Choi C. Prediction and comparison of urban growth by land suitability index mapping using GIS and RS in South Korea. Landscape and Urban Planning. 2011;**99**(2):104-114

[32] Kritikos TRH, Davies TRH. GIS-based multi-criteria decision analysis for landslide susceptibility mapping at

northern Evia, Greece [GIS-basierte multikriterielle Entscheidungsanalysen zur Kartierung von Massenverlagerungspotenzialen im nördlichen Evia. Griechenl]. Z. Dtsch. Ges. Für Geowiss. 2011;**162**:421-434

[33] Nefeslioglu HA, Sezer EA, Gokceoglu C, Ayas Z. A modified analytical hierarchy process (M-AHP) approach for decision support systems in natural hazard assessments. Comput. Geosci. 2013;**59**:1-8