Agricultural land suitability analysis in Manipur, India using GIS and AHP

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ABSTRACT

This article aims to identify potential sites for agricultural use in the state of Manipur of north east India by employing the analytic hierarchy process in a geographic information system environment in conjunction with the use of remote sensing and soil data. Within the analytic hierarchy process, each terrain variable underwent a pairwise comparison and criteria weights were assigned according to their relative importance. Eight variables were selected and used in land suitability analysis for agriculture. It was found that Manipur had 57% (12,660 km^2) of its total geographical area suitable for agriculture. However, 8126 km^2 (37%) and 1374 km^2 (6%) of the total geographical area was currently and permanently unsuitable land respectively. The distribution of suitable land varied greatly, with highly, moderately and marginally suitable land covering only 8%, 16% and 33% respectively of the total geographical area. The highly suitable agricultural land is predominantly concentrated in the Imphal valley (70%), though 90% of moderately suitable and 96% of marginally suitable land also exist in the hills. The hilly areas constitute 96% and 97% respectively of currently unsuitable and permanently unsuitable land in the state. Suitable land comprises of land with low to medium altitude, gentle to moderate slopes, soil of fine or acceptable quality, and with minimal flood risk. Unsuitable lands tend to be diametrically opposite to these attributes with steep hill slopes. The nature of distribution of land suitability types influences the agricultural pattern in Manipur. Agriculture in the hill areas comprises mainly of shifting cultivation on hill slopes, whereas in the valley region it is irrigated and permanent. This analysis of Manipur has a wider applicability since the shifting cultivation-irrigated agriculture combination is similar to that which exists across much of the highlands of South East Asia.

KEYWORDS

agriculture; analytic hierarchy process; geographic information systems; land suitability, terrain; Manipur, India

Received: 10 November 2023
Accepted: 6 May 2024
Published online: 22 May 2024

Baite, L., Bhattacharjee, N., Debbarma, J., Saikia, A. (2024): Agricultural land suitability analysis in Manipur, India using GIS and AHP. AUC Geographica 59(1), 93–107
https://doi.org/10.14712/23361980.2024.6
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1. Introduction

Terrain evaluation assesses land features such as topography, geology, soil quality, water availability, vegetation, and current land usage to determine its appropriateness for a specific activity (Beckett et al. 1972). Land evaluation analyses the essential properties of the terrain and its ability to support specific land uses sustainably over extended periods (Bandyopadhyay et al. 2009). Topographic characteristics are key to land capability and suitability analyses as they influence the irrigation system, soil quality, cost of land development, forms of agricultural plots, and crop diversity (Akinci et al. 2013; FAO 1985; Mahato et al. 2024). Topography influences the hydrological regime, climatic and meteorological conditions of a particular terrain which are important determinants of soil (Florinsky 2012; Nath et al. 2021). Soil and climate data are crucial for land evaluation and land capability classification (Sitorus 2010).

Land suitability (LS) analysis is a process of determining inherent land capabilities, its quality, potential, and suitability for different purposes (Zolekar and Bhagat 2015). Agricultural LS analysis is a way of ensuring food security in line with the United Nations sustainable development goals (SDG) (Akpoti et al. 2019). Indigenous communities leverage their traditional ecological knowledge and environmental acumen in the assessment and selection of agricultural land plots. Crops to be cultivated are chosen based on soil characteristics, insolation, and moisture availability. Relatively better agriculture sites are selected for the cultivation of rice, the principal crop. Indigenous knowledge is crucial in agricultural land suitability analysis (Feizizadeha and Blaschkeb 2013), but this method of land evaluation has limitations in the formal land use assessment. LS analyses have been undertaken concerning agroforestry in NEI (Nath et al. 2021), paddy cultivation (Mahato et al. 2024), vegetable farming (Sarkar et al. 2023), betel nut cultivation and crop acreage expansion (Hudait and Patel 2022). Being determined by several factors, LS requires a multicriteria assessment in its approach.

Multicriteria decision making is a method of processing a set of criteria into a single index of evaluation (Feizizadeh and Blaschke 2013). Numerous methods are available for multicriteria decision making such as artificial neural networks (Wang 1994), criteria matching process (Ritung et al. 2007), logical integration (Martin and Saha 2009), logic scoring preferences (Montgomery et al. 2016) and Analytic Hierarchy Process (AHP). AHP has proven to be an effective and methodical means of assessing intuition and subjective personal choices and incorporating them into objective mathematics (Saaty 2001). It provides a method to make assessments and decisions objectively using a simple pairwise comparison. The combination of GIS and AHP techniques is widely used across different disciplines (Podvezko 2009; Tempa 2022). The latter involves breaking down a decision into a hierarchy of criteria and sub-criteria and then assigning weights to each of these based on their relative importance (Saaty 2008). LS analyses deal with multiple factors that influence agriculture in varying ways. AHP uses pairwise comparison of data in which the criteria involved are compared in pairs which is simpler than taking all criteria considered at a time (Podvezko 2009).

The integration of AHP in a GIS environment has proved to be a versatile tool that has been used in a range of studies like LS analysis, groundwater potential mapping, and decision-making in diverse fields (Canco et al. 2021; Bozdağ et al. 2016; Akinci et al. 2013; Melese and Belay 2022; Hassan et al. 2020). Similar studies on paddy cultivation on parts of NEI (Mahato et al. 2024; Pawe and Saikia 2022) have been carried out. However, no such studies on Manipur have been undertaken. The majority of the population depends on agriculture and allied economic activities where shifting cultivation is the dominant agriculture method. Therefore, the objective of the present study is to evaluate LS for agricultural land use optimization using AHP in a GIS environment and to determine the distribution of land resource availability in Manipur. The hills of NEI of which the current study area (CSA) is a part are ethnically and physiographically similar to SE Asia (SEA). Therefore, this analysis has significantly wider applicability.

2. Study area

Manipur, in north-east India (NEI), extends from 23°83′N to 25°68′N latitude and 93°03′E to 94°78′E longitude (Fig. 1). The state has been referred to as a "Mini-Amazon" (Ganguly et al. 2023) being part of the India Burma biodiversity hotspot (Rai and Vanlalruati 2022) and is ecologically vulnerable (Jin et al. 2021). Imphal Valley (IV) consists of 10% of the state's TGA (22,327 square kilometers) while the surrounding Hills of Manipur (MH) constitute 90% of the tract. Geological formations in the state include Tipam, Surma, Barail, and Disang, while IV is formed of recent alluvium soils (GSI 2011). The Tipam and Surma are soft, friable and poorly consolidated arenaceous rocks forming highly dissected hills and valleys. The Barail predominantly comprises coarse, massive, well-bedded sandstone and shales. Disang is composed mainly of shales and occasional limestone blocks interbedded by sandstones. The Barail and Disang are depicted by moderately dissected hills and valleys. Each geological group exhibits varying base cation exchange capacity (CEC) of soil. The CEC (cmol/kg) in the A horizon of major soil series in the state are 9.2 (Surma), 11 (Disang), 14 in Suongpeh series and 17.3 in Leimakhong series at the adjoining zone of Disang, and Barail rocks (Sahoo et al. 2020). The hill areas generally exhibit higher soil organic

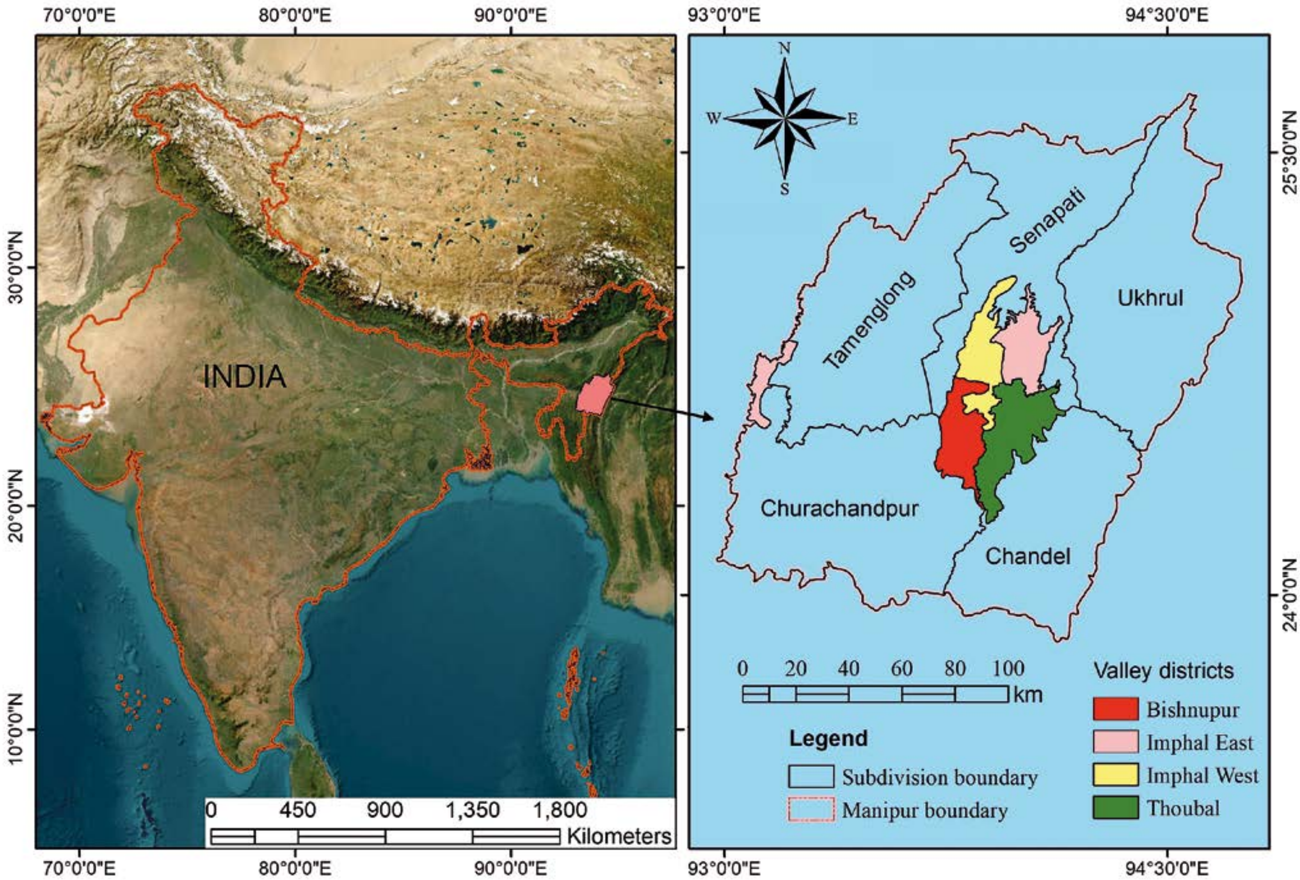

Fig. 1 Location of thestudy area.

carbon (SOC) content than IV (Roy et al. 2018). Inceptisols, Ultisols, Entisols, and Alfisols which constituted 38.4%, 36.4%, 23.1%, and 0.2% respectively of TGA are the dominant soil types (Sen et al. 1996).

Geomorphological landforms are categorized into four types based on their origin: structural, denudational, fluvial, and lacustrine. Structural origin hills and valleys are highly or moderately dissected, but some low dissected hills and valleys belong to this group. Denudational landforms, here, are usually pediplains, piedmont slopes, low hills, and valleys. The fluvial origin landforms are the old alluvial flood plain, the young alluvial flood plain, and the active flood plain. Lastly, lacustrine plains are found mostly around Loktak Lake (GSI and NRSC 2012). Fig. 2 illustrates the topography and relief of Manipur while Tab. 1 summarizes the spatial distribution. The flat and gently sloping landforms accounted for 16% of the TGA while hills and mountains make up the rest of the state. Topographically, about 84% of the TGA of Manipur is formed of hilly and mountainous terrain.

NEI has a monsoon climate (Ganguly et al. 2023). Manipur lies close to the Tropic of Cancer and acquired the characteristics of a tropical climate but north of the 25°N latitude, it has a warm temperate mesothermal climate (Dikshit and Dikshit 2014). It has a mean annual temperature of 19 °C to 20 °C and an average rainfall of 2000 mm to 2400 mm. The CSA falls within the Eastern Himalayan agroclimatic region, but it has three distinct agro-ecological zones (AEZ) (https://horticulture.mn.gov.in/soil_of_manipur.html). The warm and humid AEZ with a thermic ecosystem has a length of growing period (LGP) of 300–330 days. The hot and humid AEZ has a hyperthermic ecosystem and LPG of 270–300 days. The warm and perihumid AEZ has an LGP of 330–365 days. The AEZs are characterized by deep and fine red and lateritic soils that

Tab. 1 Areal distribution of different landforms.

Relief Types	Slope (in degrees)	Area (in km^2)	Area (in %)
Flat	< 1.5	1657	7.45
Undulating/ Gently Sloping	1.5–4.0	780	3.51
Rolling/Sloping	4.0–7.5	1252	5.63
Hilly	7.5–15	4928	22.17
Mountainous	15–20	4754	21.38
Steep/Mountainous	20–30	7029	31.62
Very Steep/Highly Mountainous	> 30	1831	8.24
Total Area		22231	100

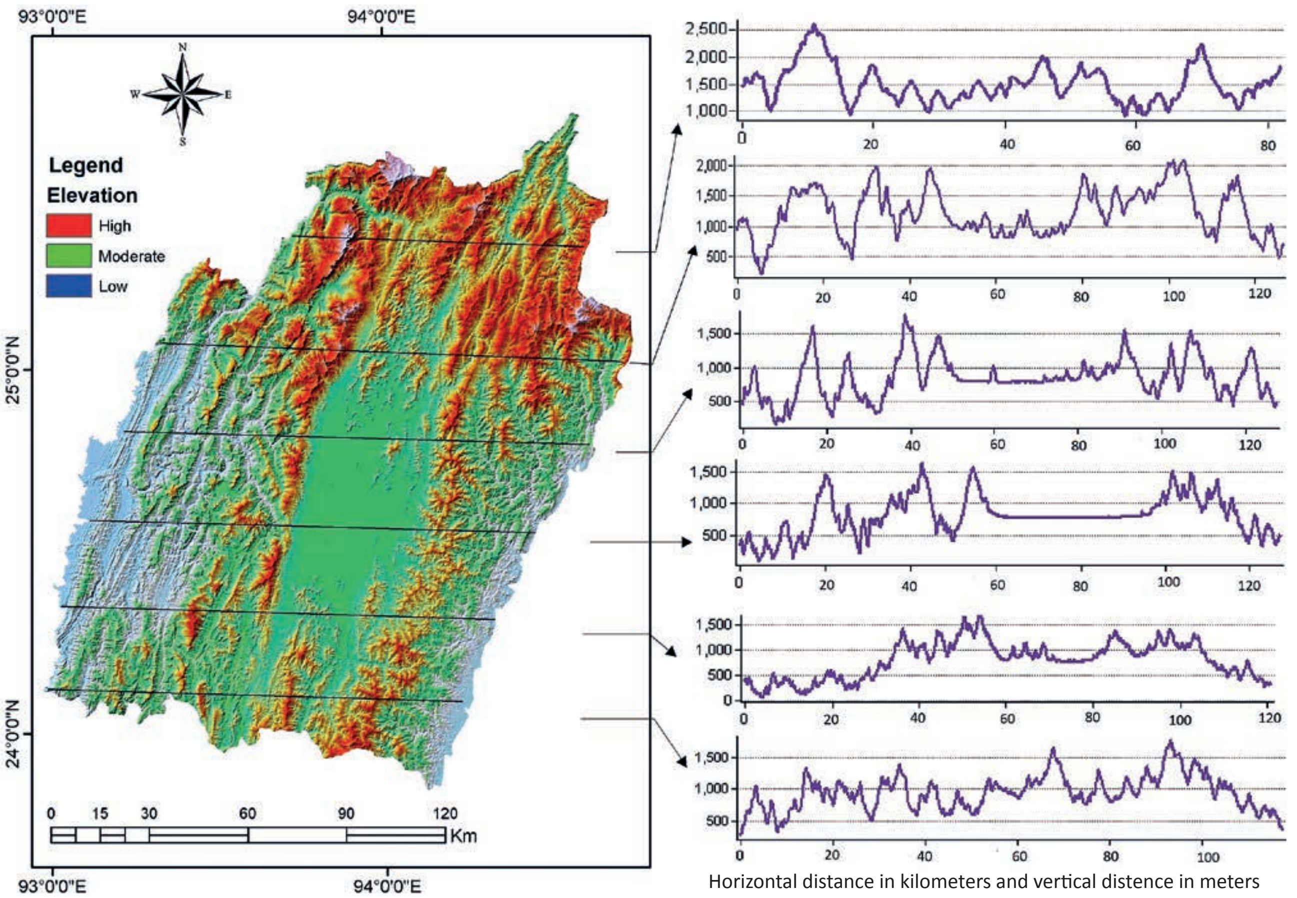

Fig. 2 Relief and elevation profile of the study area.

have available water capacity of 200–300 millimeters per meter (Sen et al. 1996).

The soils are generally hyperthermic and have low cation exchange capability and base saturation, yet it has high exchangeable calcium and magnesium ions and high organic carbon content (Sahoo et al. 2020). Despite the prevalent shifting cultivation and soil loss, agriculture can effectively continue due to the constant replenishment of soil organic through the fall of litter. The AEZ and associated soil characteristics of Manipur show the prospects for crop diversity (Sen et al. 1996). However, there are concerns regarding the effect of climate change on water resources, forests, the environment (GoM 2013), and agricultural productivity in the state (Takhell 2023). According to the CEEW (Council on Energy, Environment and Water) Report 2021, Manipur ranks 6th in the climate vulnerability index. The dependence of the population on activities like agriculture, forestry, and fishing makes them particularly vulnerable to climate change (Devi et al. 2023).

3. Data and methods

Topographic data and soil information were the main datasets used in the analysis (Fig. 3). The Shuttle Radar Topographic Mission (SRTM) (https://earthexplorer.usgs.gov) Digital Elevation Model (DEM) was used to extract topographic information (i.e. slope and altitude). The altitude and slope map of the study area were prepared using the 30 meter DEM in ArcGIS 10.8 (www.esri.com). Geomorphologic attributes such as alluvial plains, flood plains, piedmont slopes, lacustrine swamps, and marshes were acquired from the Geomorphology of Manipur (1 : 50,000 scale) from the Bhuvan web portal (https://bhuvan-app1.nrsc.gov.in/thematic/thematic/index.php). The data was prepared jointly by the Geological Survey of India (GSI) and the National Remote Sensing Centre (NRSC). We manually digitized the geomorphic units of the study area in ArcGIS. The vector file of the data was assigned separate grid codes for each geomorphic unit and converted to raster. We derived soil attributes from the soil map of Manipur available at the scale of 1 : 500,000. The map was prepared by the National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) and the Directorate of Horticulture and Soil Conservation, Manipur (https://esdac.jrc.ec.europa.eu/content/manipur-soils). The soil mapping units consisted of dominant (50% or more of the delineated area) and subdominant soil families (Sen et al. 1996). Four soil attributes – depth, erosion, drainage, and flood hazards – were digitized manually

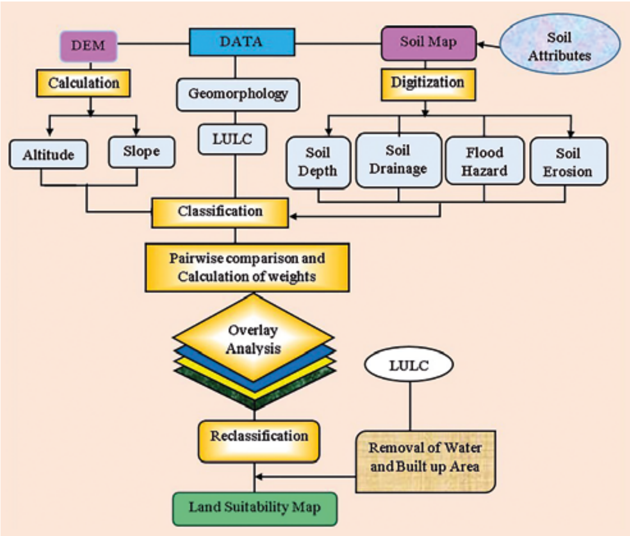

Fig. 3 Flow chart and methodology.

from the soil map in ArcGIS. Subsequently, the digitized vector shapefile representing these soil characteristics was converted into raster datasets. The global land use and land cover (LULC) data available at 15-meter resolution was downloaded from the ESRI website (https://livingatlas.arcgis.com/landcover). The LULC classes used in this analysis were built-up, bare ground, crop or fallow lands, flood vegetation, range and open grassland, and dense forest. Of these, the extent of the bare ground class was negligible, crops and fallow land constitute irrigated permanent agricultural lands (PAL). The LULC was reclassified into five classes after combining similar classes for the present study. Finally, all the raster data prepared for LS analysis were resampled into a uniform spatial resolution of 100 meters and projected into a uniform UTM coordinate system (Fig. 4).

3.1 Analytic Hierarchy Process (AHP)

AHP decision making involves several steps: identification of variables, hierarchical structuring of the variables, pairwise comparison of each element, and calculation of weights. The involvement of multiple criteria and intricate relations among the elements in AHP makes the assignment of criteria weight a complex process. However, AHP arranges criteria in a hierarchical structure and enables a pairwise comparison of the elements. This technique is simple and efficient as it allows qualitative estimates of experts to be converted to quantitative ones (Podvezko 2009; Gupta and Dixit 2022).

A comparison between two elements was performed to determine how many times one element was dominant over the others (Saaty 2008). The pairwise comparison was based on subjective assessment and intuitive judgment among the criteria (Saaty 2001). The criteria used in LS were judged based on their relative importance (Tab. 2) Saaty (2008). We performed a pairwise comparison based on information about altitudes (Allan 1986), slopes (FAO 1976) and soil attributes (FAO 1967; Grose 1999) and the pairwise judgment in similar studies (Hudait and Patel 2022; Mahato et al. 2024; Zolekar and Bhagat 2015). The opinions of elderly farmers, especially in hill agriculture, and the authors' intuition during the field observations played a crucial role in pairwise judgment. Based on Saaty's preference scale, slope exacted a significant importance over soil depth, drainage, erosion, and LULC respectively (Tab. 3). The pairwise matrix consists of $n(n-1)/2$ elements of comparison for n numbers of elements (Akinci et al. 2013). Interpretation of other elements in the pairwise matrix was the same as detailed above.

When performing pairwise comparisons inconsistencies often occur. The logical consistency of the pairwise comparison can be determined by the consistency ratio (CR) as suggested by Saaty (Akinci et al. 2013). The validity of the pairwise comparison matrix was confirmed by CR with an upper limit of 0.10 (Saaty 2008). The calculated CR of the pairwise matrix was 0.028 (Tab. 4) well within the threshold value of 0.1. Therefore, the pairwise matrix obtains a sufficient degree of logical consistency in the pairwise comparison.

Tab. 2 Fundamental scale of comparison for pairwise comparision (Saaty 2008).

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment strongly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Extreme importance	Preference for one activity over the other is highest
2, 4, 6 and 8	Intermediate values	When compromise is needed
Reciprocals	If activity i has one of the above numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i.	

Tab. 3 Pairwise comparison matrix of criteria based on Saaty's fundamental scale (2008).

Criteria	Slope	Soil depth	GM	Altitude	Soil drainage	Flood	Soil erosion	LULC	Criteria weight (CW)
Slope	1	3	4	4	5	6	7	9	0.34
Soil depth	1/3	1	3	4	5	6	5	8	0.24
GM	1/4	1/3	1	1	3	5	5	7	0.13
Altitude	1/4	1/4	1	1	3	4	3	5	0.11
Soil Drainage	1/5	1/5	1/3	1/3	1	3	3	5	0.07
Flood	1/6	1/6	1/3	1/4	1/3	1	2	3	0.06
Soil Erosion	1/7	1/5	1/5	1/3	1/3	1/2	1	2	0.03
LULC	1/9	1/8	1/7	1/5	1/5	1/3	1/2	1	0.02

3.2 Description of criteria used in LS evaluation

Altitude: Altitude significantly influences agricultural land use and cropping patterns, offering opportunities for specialized agriculture tailored to specific elevation zones (Allan 1986; Bonan 2015). The altitude of the CSA was categorized into five classes (Tab. 5). Crops and livestock thrive at altitudes below 180 meters but above this zone, some crops are vulnerable to frost (Grose 1999). Limited crops thrive at 380–500 meters and there is little grazing ground available at 600–900 meters. Beyond 900 meters elevation, no activities are possible.

Slope: Slopes are the basis for the FAO classification of agricultural LS based on the degree of limitation of mechanization, trafficability, and accessibility. Slopes are a primary factor in site selection for agricultural land use (FAO 1976) since they are related to soil depth, texture, moisture, and nutrient availability. They can be categorized into five classes (Tab. 5) based on the limitations they present to different agricultural activities (FAO 1976). For instance, slopes less than 4° have more than 90% tractor efficiency while only primitive implements can be used on slopes greater than 35°.

Geomorphology (GM): Geomorphic units like alluvial and flood plains are ideal for agriculture due to the high soil fertility in these zones. It is an important component of LS analyses for paddy cultivation (Mahato et al. 2024; Anusha et al. 2023). Eight geomorphic units are available in the CSA which were assigned weights and ranked according to their importance for agriculture (Tab. 5).

Soil depth: It determines the volume of soil that can be used by crops. Deep soils are preferred for agriculture (FAO 1967). Types of soil depth in CSA are deep (> 100 cm), moderately deep (75–100 cm), moderately shallow (50–75 cm), and shallow (25–50 cm). The effective rooting in crops is restricted by soil depth in varying degrees as severe, moderate, slight, and no limitations depending on the thickness of the soil horizon (Bhaskar et al. 2021). Soil depth as provided in the soil mapping units is given in Tab. 5.

Tab. 4 Pairwise comparison result.

Maximum Eigen Value (λ_{max})		8.280
Consistency Index (CI)	CI = (λ_{max} – n)/(n–1)	0.040
Consistency Ratio (CR)	CR = CI/RI	0.028
Random Index (RI)		1.410

Soil drainage: It is determined by soil texture, topography, and water table which control air and nutrient availability thus determining soil productivity (Sen et al. 1996). Soil drainage efficiency was interpreted from an earlier analysis (Grose 1999) and were assigned weights accordingly. Soil drainage classes found in CSA ranged from extremely poor to excessively drained soils (Tab. 5).

Flood hazard: The state has slight, moderate, and severe flood hazard zones and most of the MH faces slight or no flood hazards. However, areas along the river banks are prone to seasonal flooding. IV is vulnerable to occasional severe flooding due to heavy runoff and low infiltration capacity of the soil as a result of land degradation in the catchment area (https://mastec.nic.in/images/Completed_projects/ReportFloodHazard.pdf).

Soil erosion: Soil erosion in the CSA ranged from slight to severe (Tab. 5). The IV has very slight or no erosion but the rest of Manipur faces moderate to severe erosion attributable to the hilly topography, land degradation, and heavy rainfall (Roy et al. 2018). Slight erosion manifests as damaged surface horizons, yet soil biotic conditions remain undisturbed (Jahn et al. 2006). Moderate erosion displays evident signs of soil loss, impacting biotic functions. The annual soil loss in terms of tons per hectare through slight, moderate, and severe erosion amounted to 10–20, 20–40, and >40 tons/ha/year respectively (NRSC 2019).

LULC: Cropland lies fallow during the post-harvest or off-season. Rangeland is an open area covered by homogeneous plants such as grass and stunted vegetation that is open to other land uses. On the other hand, built-up and water bodies cannot be converted into PAL. Flooded vegetation is covered with a variety of plants like paddy, grass, and shrubs in seasonally flooded areas (Karra et al. 2021). Forests with trees higher than 15 meters were identified as dense forests.

Tab. 5 Criteria and sub-criteria weight assignment.

Main criteria	CWCW	Criteria level two	Score (x)
Slope classes	0.34	Level to gentle	9
		Gentle slope	7
		Moderate slope	5
		Steep slope	3
		Very steep slope	1
Soil depth	0.24	Deep soil	7
		Deep associated with moderately deep soil	6
		Deep associated with shallow soil	5
		Moderately shallow and deep soil	4
		Other soils	1
Geo-morphology	0.13	Alluvial plain	9
		Flood plain	9
		Pediment pediplain complex	7
		Piedmont slope	7
		Low dissected hills and valleys	5
		Moderately dissected hills and valleys	5
		Lacustrine swamp and marsh	3
		Highly dissected hills and valleys	3
		Water body	1
Altitude zones	0.11	0-150	5
		150-300	4
		300-450	3
		450-600	2
		600 Above	1
Drainage effectiveness	0.07	Well drained	7
		Well drained associated with poorly drained	5

Main criteria	CWCW	Criteria level two	Score (x)
Drainage effectiveness	0.07	Well drained associated with excessively drained	5
		Somewhat excessively drain associated with well drain	4
		Poorly drained associated with well drained	3
		Excessively drained associated with well drained	3
		Others	1
Flood hazard	0.06	None	5
		Slight flooding	4
		Moderate and severe	3
		Moderate to severe	2
		Severe and slight	1
Soil erosion	0.03	No erosion	9
		Very slight erosion	9
		Slight erosion	7
		Moderate erosion	5
		Moderate	5
		Low erosion	3
		Moderate to severe erosion	3
		Moderate erosion; severe in parts	3
		Severe erosion, moderate in parts	1
		Severe	1
LULC	0.02	Crops/fallow lands	7
		Range, open grassland, expose soil/rocks	5
		Flood vegetation, rice paddy	4
		Trees higher than15m, dense vegetation	3
		Others	1

Criteria weights (Fig. 4) of the elements were calculated by normalizing the pairwise comparison matrix (Tab. 3). The normalized pairwise matrix was created by dividing the column elements of the matrix by the sum of the respective columns. The sum of the elements of the rows in the matrix was calculated, then each sum of a row was divided by the sum of their total (Akinci et al. 2013; Podvezko 2009). The weight vector of the criteria ranged from 0 to 1 the sum of which equalled 1 (Tab. 5). Assignment of the sub-criteria rank was done on a scale between 1 and 10. For instance, slope < 4° was assigned a score of 9, slope 8–20° was given 5 while very steep slopes > 35° scored only 1. The higher the score the more favourable the sub-criteria and minimal constraints were posed for agriculture. Similarly, the ranks for other elements of the sub-criteria were assigned based on their importance to agriculture. Scores were allocated based on the degree of suitability or constraints of the sub-criteria for agricultural application. These were in concordance with similar analyses (Anusha et al. 2023; Bandyopadhyay et al. 2009; FAO 1976; Grose 1999; Hudait and Patel 2022; Mahato et al. 2024; Zolekar and Bhagat 2015).

The weighted sum overlay analysis for LS evaluation was run in the Spatial Analyst tool of ArcGIS 10.8 using the formula (Zolekar and Bhagat 2015; Mahato et al. 2024):

$$LSI = \sum_{i=1}^{n} CWiXi$$

Where LSI is the land suitability index, *CWi* indicates the weight of the main criteria, *Xi* represents the assigned sub-criteria score of the i^{th} land suitability criteria, and *n* denotes the total number of selected parameters.

The output of the weighted sum overlay analysis yielded continuous raster data where the maximum value indicated the most suitable land and the least

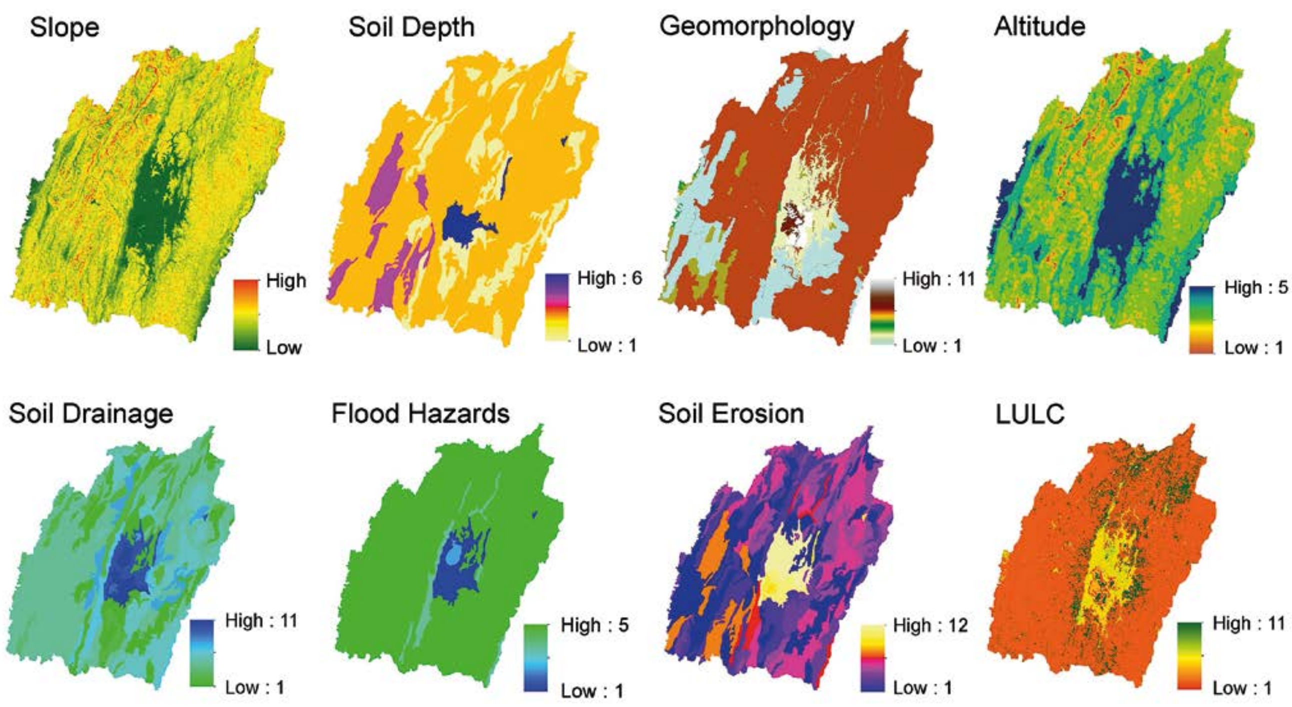

Fig. 4 Ranked criteria.

value represented unsuitable land. The continuous data was reclassified into five classes according to FAO (1976) as highly suitable, moderately suitable, marginally suitable, currently unsuitable, and permanently unsuitable (Fig. 5). The LS classification system of FAO was employed since it has been adopted by several studies (Hudait and Patel 2022; Kazemi and Akinci 2018; Zolekar and Bhagat 2015). The assignment of different suitability classes was based on Jenk's classification method. This method works on the principle of maximum homogeneity of values within a class. Jenk's classification has become a standard geographic classification algorithm (North 2009) in which the geographical environmental unit has a minimum deviation from the mean class. It is a "data classification method designed to determine the best arrangement of values into different classes" (Chen et al. 2013) giving optimal results. To determine the extent of LULC in different LS categories, the latter were overlaid on the former. The area covered by each LULC class overlapped by the LS classes was evaluated.

4. Results and discussion

Land Suitability is divided into two sub-groups – suitable land (S) and not suitable land (N). The former was further subdivided into three classes, namely, highly suitable (S1), moderately suitable (S2), and marginally suitable (S3). N was divided into currently unsuitable (N1) and permanently not suitable (N2) categories (Fig. 5). The areal distribution of different land suitability classes in Manipur exhibited significant variation (Tab. 6).

S1 was characterized by level or gentle slopes, deep soils, and was situated in the low altitude zone. Soils were either well or poorly drained and experienced slight to moderate flooding, and slight to no erosion. This land category enabled the cultivation of wet paddy during the monsoon season and vegetables in other seasons (Fig. 7A). S1 was well-suited for agriculture and had immense potential for intensive agriculture (Zolekar and Bhagat 2015). S2 land had a gentle slope and occurred at slightly higher altitudes (Fig. 7B). Soils were moderately deep to deep and were generally associated with slight to moderate erosion. Such lands were cultivable and productive provided suitable conservation and management system were practiced on them (Zolekar and Bhagat 2015). Areas under S2 with moderate to gentle slopes were used in terrace cultivation while those prone to flooding and waterlogging were suitable for paddy cultivation. S3 land was the most widespread suitability

Tab. 6 Area under different land suitability classes.

Suitability Class	Area in km^2	Area in %
Highly Suitable Land (S1)	1793	8
Moderately Suitable Land (S2)	3588	16
Marginally Suitable Land (S3)	7297	33
Currently Not Suitable (N1)	8126	37
Permanently Not Suitable (N2)	1374	6
Total	22158	100

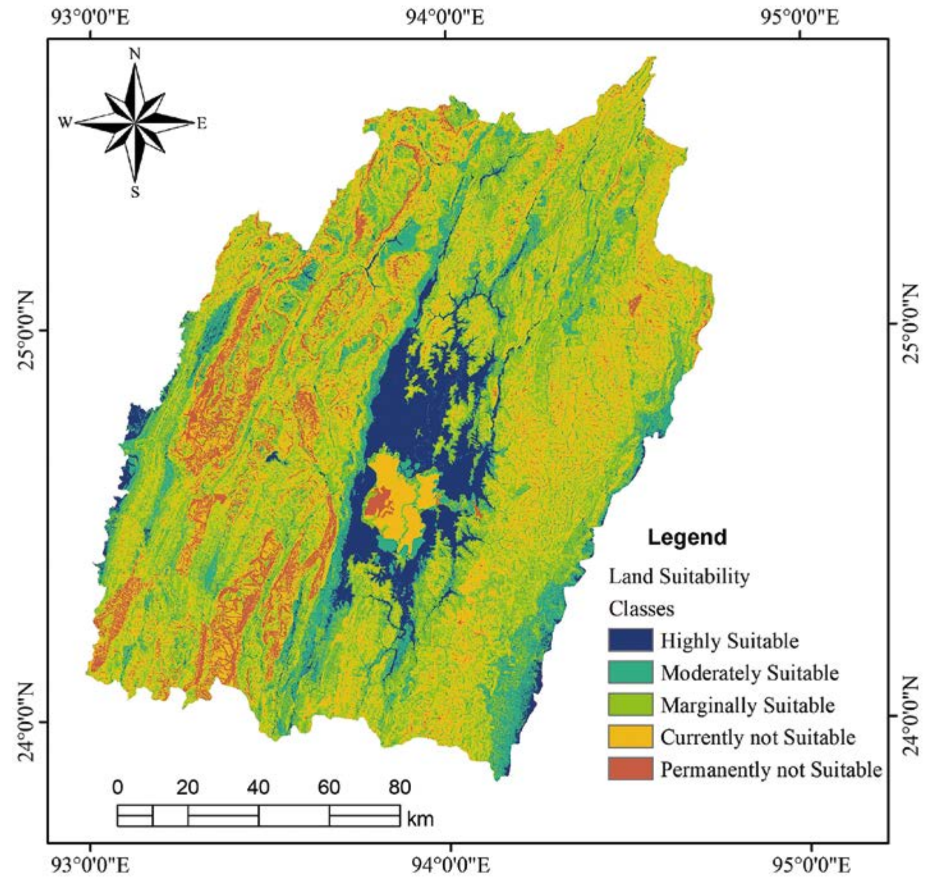

Fig. 5 Land suitability.

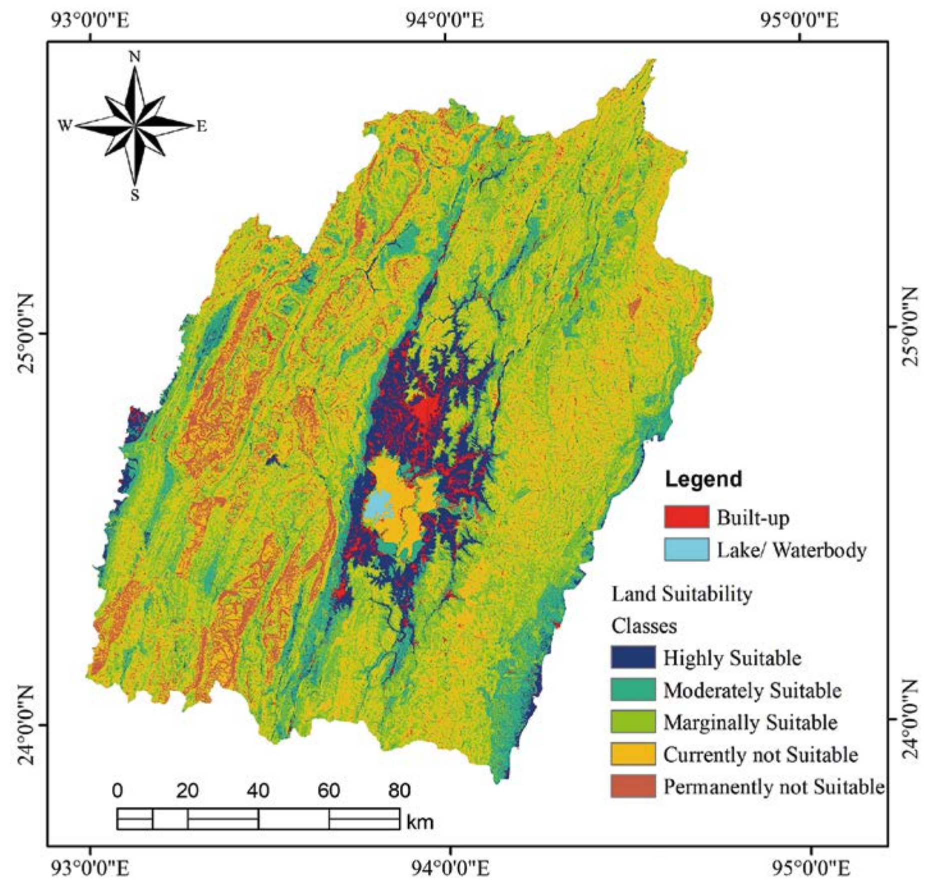

Fig. 6 Land suitability (built-up and water-body removal).

Fig. 7A Wet paddy cultivation on highly suitable land (Date: 20/8/2019).

Fig. 7B Paddy cultivation on moderately suitable land (Date: 04/10/2021).

Fig. 7C Paddy cultivation on marginally suitable land (Date: 02/10/2021).

Tab. 7 Land use land cover distribution in different districts of Manipur.

Districts	Area of LULC in square kilometres					
	Built-Up	Agriculture	Scrub	Flood vegetation	Forest	Water
Bishnupur	71	203	32	88	23	63
Chandel	30	35	322	0	2795	2
Churachandpur	56	55	347	0	4234	19
East Imphal	107	200	37	0	250	4
Senapati	95	84	755	0	3960	9
Tamenglong	37	12	176	0	3960	9
Thoubal	119	342	73	24	111	45
Ukhrul	46	6	529	0	3870	1
West Imphal	130	239	30	18	50	20

class found on moderate to steep slopes of hills at higher altitudes, with no flood hazards, characterized by excessive soil drainage and moderate to severe soil erosion. Agriculture, especially terrace farming, was possible on marginally suitable land with proper conservation and management strategies (Zolekar and Bhagat 2015). S3 were devoted mainly to shifting cultivation in MH (Fig. 7C). Due to significant limitations in S3, production was low, and also expenditure on farm inputs tended to rise. As a consequence, the profit of farm production was adversely affected (Ritung et al. 2007). N1 and N2 lands were characterized by steep slopes and found at higher altitudes where soils were shallow and prone to severe erosion. Although the N1 and N2 classes were of little value from the agricultural perspective, they were generally undisturbed and perennially under vegetation. Thus, different LULC classes (Tab. 7) distributes across various LS categories.

The area suitable for agriculture constitutes roughly 57% of the TGA of Manipur, with the remaining 43% land being unsuitable for cultivation. Of the total 1793 km^2 of S1 class, 23% was built-up and about 1% had reservoir water from construction of dams resulting in the submergence of fertile plains along the river course. The area of LULC under different LS classes is given below (Tab. 8). The bulk of S3 (86%) was under forest and scrubland (12%) while built-up and cropland were insignificant. Manipur had 4565 km^2 highly suitable and 10482 km^2 suitable for agroforestry (Nath et al. 2021). The estimate of land capability Class II in the state stood at 9% of its TGA (Sen et al. 1993). The soils in this capability class had slight limitations but were cultivable with proper management strategies. The S1 (highly suitable land) in this study (8%) was close to the area of IIws and IIIw combined (9.1%). Manipur has 52.87% of S1 devoted for PAL (Tab. 8). This LS class was characterized by gentle slopes, high annual rainfall on floodplains and was conducive to paddy cultivation (Mahato et al. 2024).

About 7% (119 km^2) of S1 land in Manipur was scrub forest or range land. Scrub or range lands are degraded forests with minimal vegetation cover. Therefore, S1 has the potential to be converted as PAL without unduly adverse effects occurring on the green cover. The extent of S1 within forest cover is 16% or 288 km^2 and can be expanded for PAL. The share of S1 available for expansion into PAL is small compared to S2. Additionally, conversion from forest land to PAL is not an environmentally friendly course of action. Although 3243 km^2 of S2 class is available for conversion into PAL it remains under-utilized. S2 has the potential for expansion and improved sustainable agriculture. Manipur depends on imported food grains from other Indian states yet 52% of the state's population is engaged in agriculture and allied sectors (GoM 2015). One important reason for the limited expansion of PAL is the high cost of land development and maintenance. There is a pressing need for the expansion of sustainable agriculture. Currently, agriculture expansion is feasible in S1 and S2 LS classes,

Tab. 8 Area of LS class under different LULC classes in Manipur.

Land suitability class	LULC classes (area in km^2)						
	Built-up	Fallow / crop (PAL)	Flood vegetation	Range / scrub	Dense forest	Water-body	Total
S1	413	948	1	119	289	23	1793
S2	130	168	10	439	2804	36	3588
S3	121	14	6	854	6251	31	7279
N1	22	41	78	785	7123	77	8126
N2	3	2	35	94	1236	4	1374

however, it entails adequate financial investment. The S3 class in the MH (Hills of Manipur) is used for shifting or jhum cultivation. Among the NEI states, Manipur has the highest area under shifting cultivation and the minimum annual area under it is 900 km^2 (Choudhury and Sundriyal 2003). It is not suitable for PAL due to topographic constraints. Floods and water logging are the main limitations in the IV of Manipur. Yet the latter contributes a major share of the state's agricultural output due to favourable climatic, hydrogeologic and topographic conditions (Thockchom and Kshetrimayum 2019).

The share of S1 class is highly inequitable among the districts (Tab. 9). The four districts in IV account for 71% of the S1 land in Manipur. However, due to the concentration of population and large scale developmental activities in the IV, S1 lands were converted to other land use. The MH accounts for only 29% of S1 exhibiting the hill-valley contrast in the availability of suitable agricultural land in the state. In terms of spatial extent, the former spreads over 20,089 km^2 i.e. 89.98% of the TGA of the state. Our analysis shows that S1 land for PAL is inadequate in Manipur, though the average size of operational land holding was 1.14 hectares in 2015–2016 (MoA&FW 2018). According to the latest Agriculture Census (2015–2016), the total operational land holding in the state was 1720 km^2 out of which 45.9% lie in the hill areas (MoA&FW 2018). In the MH, irrigable lands suitable for PAL are scarce, therefore, people have little option than to take recourse to shifting cultivation. The latter is an age-old practice rooted in their culture. Additionally, people are involved in economic activities such as fuelwood collection, charcoal making, and collection of forest products. In the valley region, the S1 class is prevalent, and wet paddy cultivation dominates agriculture, while animal husbandry, fish farming, and vegetable crops are practiced as well.

The man-land ratio is high but the quality of land is poor in MH due to topographic constraints. The availability of S1 land in IV and MH is highly inequitable (Tab. 10). This resulted in limited accessibility, high cost of agriculture management, difficulties in the transportation of farm produce. In the IV of Manipur land is scarce and the man-land ratio is low. Yet, it is endowed with favourable natural conditions such as low soil erosion and fertile alluvial soil, and social factors like accessibility, market, and modern agriculture equipment. Historically, the hill and valley people were one people but the preference for an agricultural system as a result of distinct geographical attributes has caused an economic gap and other cultural differences to develop over time (Phanjoubam 2005). The distinct geographical entity in Manipur, now, forms culturally and economically different populations in the state. The hill dwellers are at a relatively disadvantageous position vis-vis their counterparts in the valley in terms of agriculture and allied opportunities.

In addition to the terrain factors, the effect of global climate change on agriculture production remains an unavoidable issue. The erratic and changing pattern of precipitation in the past few years resulted in low crop yield (Takhell 2023). There are perceptions of climate change effects on agriculture among the farmers in the NEI region (Devi et al. 2023; Baruah et al. 2021). That Manipur is vulnerable to floods and designated as a flood hotspot (Mohanty and Wadhawan 2021) poses a challenge to its agricultural sector. Additionally, extreme weather events that are projected to get accentuated are slated to affect crop yields (Roy et al. 2018). The situation Manipur is faced with is not dissimilar to that faced in other parts of highland SEA (Boral and Moktan 2022).

Topographic and soil data are essential criteria in the LS analysis (Akinci et al. 2013; Kazemi and Akinci 2018; Zolekar Bhagat 2015) and climatic data are sometimes, but not always, incorporated in studies dealing with specific crops (Nath et al. 2021). The selection of criteria for LS analysis varies among authors based on the specific objectives of their study and the geographical characteristics of the study area

Tab. 9 Area of land suitability classes in different districts.

Districts	S1		S2		S3		N1		N2	
	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Bishnupur	234	13	53	2	35	1	118	1	40	3
Imphal East	329	18	116	3	104	1	42	1	0	0
Imphal West	342	19	47	1	28	0	71	1	0	0
Thoubal	359	20	137	4	92	1	120	1	6	0
Chandel	145	8	727	20	1187	16	1079	13	16	1
Churachandpur	150	8	802	22	1541	21	1644	20	539	39
Senapati	140	8	655	18	1269	17	1294	16	112	8
Tamenglong	42	2	502	14	1311	18	1739	21	585	43
Ukhrul	52	3	549	15	1712	24	2018	25	75	5
Total	1793	100	3588	100	7279	100	8126	100	1374	100

Tab. 10 Absolute man-land ratio.

Regions	District	Population (2011)	S1 Area (km^2)	Person / km^2
Imphal valley	Imphal East	456113	709	643
	Imphal West	517992	558	928
	Bishnupur	221422	496	446
	Thoubal	422168	514	821
Manipur hills	Senapati	479148	3271	146
	Churachandpur	274142	4570	60
	Ukhrul	183998	4544	40
	Tamenglong	140651	4391	32
	Chandel	144182	3313	44

(Mahato et al. 2024). The present analysis being concerned with agriculture suitability in general in both the tropical (Awb) and humid warm temperate (Cfb) climates of Manipur (Dikshit and Dikshit 2014) felt that climatic data was not an overriding requirement. The climatic conditions in Manipur are typically conducive to agriculture (Sen et al. 1996) hence climatic parameters was not included in the LS analyses.

5. Conclusion

The rationale behind this analysis was to consider agriculture land suitability in Manipur that would have applicability to other hill regions in SEA. The use of the AHP technique in a GIS environment has simplified the terrain evaluation process by analyzing soil and topographic data. The findings show that S1 is scarce: about half of its area is devoted to cropping and settlement. In the remaining portion of S1, there is potential for expansion of PAL at the cost of forest and scrubland. The majority of the S2 and S3 lands are found in the MH where shifting cultivation has been a traditional practice for sustenance. However, the operation of shifting cultivation accelerates deforestation and environmental degradation in the state, calling for the need for research to identify a more suitable and sustainable method of cultivation. Soil erosion is a major concern in the hills whereas flooding and water logging are the challenges in the valley. The analyses of land capability is necessary in the hill-valley complex of Manipur and it is hoped would add to the scanty literature pertaining to Manipur in this respect.

Acknowledgements

The authors acknowledge using the computing facilities at the Prof. M.M. Das Advanced Study and Resource Cell at the Dept. Of Geography, Gauhati University.

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