



A Multi-Criteria Decision-Making Approach for Land Suitability Assessment for Tea Cultivation in Hilly Aizawl District in Mizoram, India

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Abstract

Geographic Information System (GIS) can be a strong tool for determining the environmental limitations of sustainable tea cultivation. Aizawl, a hilly district, is mostly covered by steep slopes and considered unsuitable for intensive agricultural practices. The present chapter attempts to find the potential land suitability for tea cultivation in Aizawl using geospatial technology. In this regard, raster information of topographic, climatic, hydrological, and soil properties have been intergraded into the GIS environment. A subjective ranking method has been implemented for weightage measurements of those different properties. Then, a relatively new multi-criteria decision-making approach, Combined Compromise Solution (CoCoSo), is used for the desired solution. After that, the suitability classes are divided into five potential classes using the natural breaking method. The result reveals that around a quarter of the total area is very highly suitable (23.74%) for tea cultivation, followed by high (34.89%), moderate

(26.34%), low (12.05%), and very low (2.98%) suitability areas. While the very highly suitable areas are found on the steep slopes, the very low suitability areas are located on the area's central and eastern sides. Due to insufficient ground information, it has yet to be possible to implement proper validation methods. Farmers' perception and location of existing Jhum land are used to validate the Kappa coefficient, which is 87.27%. The present chapter will be helpful for policymakers and the agricultural department for proper economic development in the district.

Keywords

CoCoSo · Land suitability · Aizawl · Kappa index

9.1 Introduction

Land evaluation assessment is a fundamental technique for different types of planning like agriculture, housing, industrialization, etc. Land use denotes the sociocultural function of humans on landmass, whereas land cover defines the biophysical attributes of land in a specific land unit (Layomi Jayasinghe et al. 2019). Agriculture is the backbone of the Indian economy. However, because of their climatic and topographic conditions, the northeastern states of India are limited in

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agriculture practices. In the last few decades, multi-criteria decision-making (MCDM) methods have been widely used by researchers in different fields like groundwater potentiality mapping (Barman and Biswas 2022), groundwater delete (Basak et al. 2021; Mandal et al. 2022), flood susceptibility mapping (Mitra and Das 2022; Mitra et al. 2022; Khosravi et al. 2019), landslide susceptibility mapping (Aslam et al. 2022) etc. The MCDM has better accuracy in decision making than single criteria decision making as it intergrades different criteria in a decision (Velasquez and Hester 2013). When choosing a suitable MCDM technique from the many MCDM problems available, there is always some degree of uncertainty (Abrishamchi et al. 2005). As a result, no single method can solve the MCDM issue. Guitouni and Martel (1998) have provided some criteria for choosing an effective MCDM approach. However, the MCDM model, such CoCoSo, has been widely used by several scientists (Peng et al. 2020; Stanujkic et al. 2020; Luo et al. 2021). Evaluating the soil's compatibility with tea is essential to maximize productivity and provide corrective advice for improved crop management. Decision-makers can create appropriate management actions such as new planting, infilling, replanting, adopting climate-friendly best practices, and diversification, to boost the productivity of the land using the suitability analysis to identify limiting variables (Das et al. 2017). The aforesaid is accomplished by identifying marginally suitable locations, which enable decision-makers to recognize such elements and take appropriate action. A thorough investigation must be done to determine the optimum use of the land in unproductive estates while considering other factors. Additionally, this enables stakeholders to pinpoint new sites where tea can be grown per the crop's needs while highlighting the land unit's advantages.

9.2 Background of Tea Cultivation in Mizoram

The Naga, Manipuri, and Lushai hills along the Indo-Burmese border are considered the tea plant's natural habitat in India (Panabokke et al.

2008). Tea was first cultivated in Mizoram in the Biate village headed by Thangchuanga. Later, the cultivated area was increased to one *bigha* plot in 1935 by the villagers on Halzawl hill, followed by those on Tuilut hill in 1943 (The Telegraph online, June 21, 2022). A new land use policy in Mizoram in 1995 brought tea cultivation under the Soil and Water Conservation Department focusing on Biate village, where 325 families directly depended on it. In 2004, tea cultivation was increased to about 343 small gardens existing at the time. It was boosted when the Governor of Mizoram, A. K. Kohli, inaugurated the first tea factory at Ngopa, which had an annual production capacity of 400 tonnes (The Telegraph online, June 21, 2022). However, the Mizoram government took further initiatives for tea cultivation in 2011, where 115 households of Biate village were provided assistance for tea cultivation. As per present statistics, about 877.15 hectares of areas in Mizoram are being cultivated for tea (Eastern Mirror, Feb 24 2022).

9.3 Materials and Methods

9.3.1 Study Area

The district Aizawl is centrally located between 23° 19'N, 92° 38'E and 24° 24'N, 93° 13'E in the northern portion of the northeastern state of Mizoram in India (Fig. 9.1). The dissected and undulated topography is a major barrier for extensive agriculture practices. The temperature in the district is very comfortable. While the summer temperature ranges between 20 and 30 °C, winter temperature varies between 11 and 12 °C (District Disaster Management Plan, Aizawl 2019). The rainfall here is mostly caused by the southwest monsoon and amounts to 2500 mm annually (Barman et al. 2023). Two perennial rivers, namely Tlang and Tuirial, bound the district along its western and eastern sides, respectively. According to the Census of India, 2011, the district has a population of 400,309, and the population density is 112 persons per square kilometer. The local people practice *Jhum* cultivation as their traditional way of life.

According to statistics by the Department of Agriculture (2020–2021), the 19,080 ha area is under *Jhum* land, and their productive power is 1331.71 kg/Ha.

9.3.2 Database

The present chapter includes topographic factors, namely elevation, slope, and aspect; climatic factors like annual average rainfall and temperature; and hydrological factors, namely distance to the river and lastly lithological factors, such as soil organic nitrogen content and (organic) carbon content used to evaluate land suitability for tea cultivation in Aizawl district of Mizoram. An intensive literature survey was pursued to select land suitability conditioning factors (Table 9.1). Firstly, topographic factors are prepared from

ASTER 30 m Digital Elevation Model [Earthdata Search|Earthdata Search (nasa.gov)]. Further, elevation, slope, and aspect thematic layer were prepared in ArcGIS 10.4 environment. For annual average rainfall and temperature, high-resolution gridded data sets of the climatic research group were used (Harris et al. 2020).

The growth of a tree is sensitive to various topographic and climatic factors such as slope, elevation, aspect, distance to a river, amount of precipitation, temperature, and nature of the soil, and so forth. The slope is the first controlling factor for tree growth which controls the runoff intensity, soil erosion, and nature of drainage. It also affects the percentage of soil nutrients such as organic carbon, and nitrogen. Generally, the slope between 5° and 25° is considered suitable for tea cultivation, while a slope gradient beyond 25° is unsuitable for tea cultivation (Das et al.

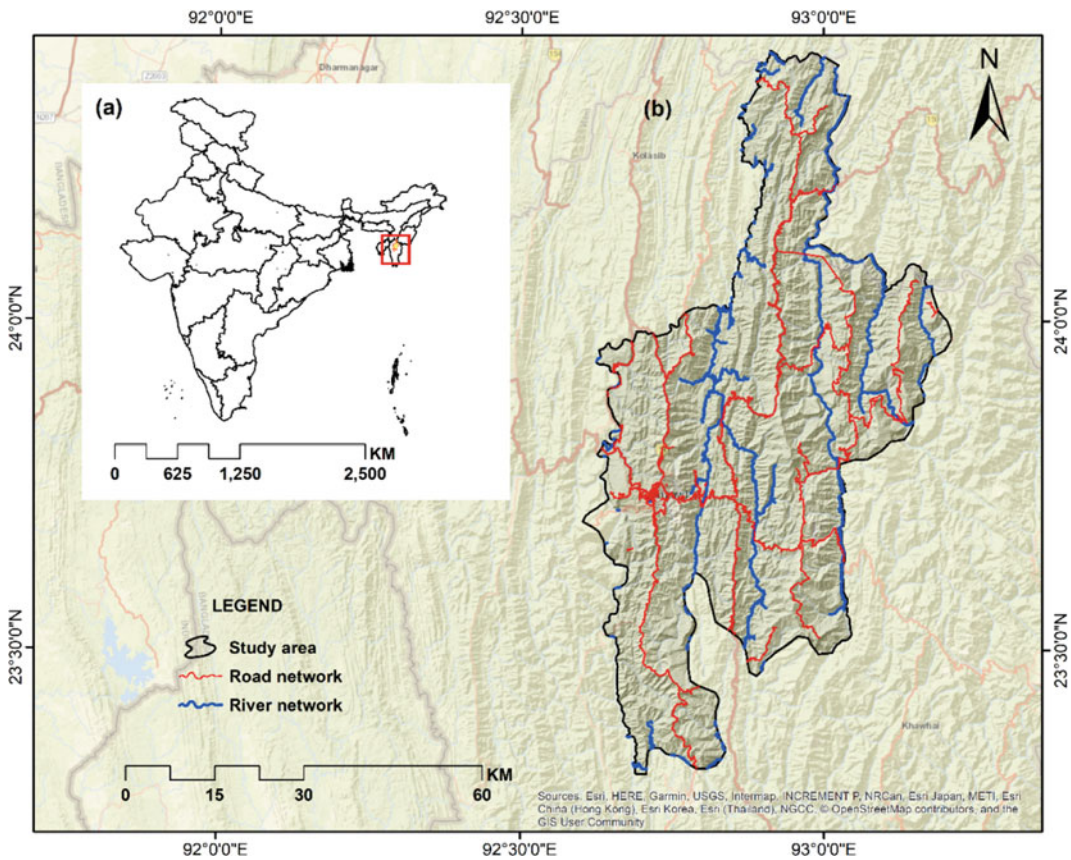


Fig. 9.1 Location of the study area: a India and b Aizawl district with river and road networks

Table 9.1 Literature survey for selection of conditioning factors

Factors	Slope	Elevation	Aspect	Rainfall	Temperature	Dist. to river	Soil
Layomi Jayasinghe et al. (2019)	✓	✓	✓	✓	✓		✓
Das et al. (2020)	✓	✓		✓	✓	✓	✓
Rahaman and Aruchamy (2022)	✓	✓		✓	✓		✓
Bo et al. (2012)	✓	✓	✓	✓	✓		✓
Panabokke et al. (2008)	✓						✓
Ashraf et al. (2020)	✓	✓	✓	✓		✓	✓
Chen et al. (2022)	✓	✓	✓	✓	✓	✓	✓
Gahlod et al. (2017)							✓
Xing et al. (2022)	✓	✓	✓	✓	✓	✓	✓

2020). Due to the water logging problem, flat areas are unsuitable for cultivation. Elevation influences the soil depth. The tea plant prefers a damp environment, not a waterlogged area because high water can destroy the plant root. Aspect can be defined as the direction a slope faces. Physical factors like the amount of solar radiation received, rainfall received, soil moisture, etc., directly depend on the aspect. In case of climatic factors, annual rainfall and temperature play a significant role in the growth of tea plants. Generally, a minimum of 1000 mm of annual rainfall is required during the growing season, while the optimum amount ranges between 1800 and 2000 mm (Han and Li 2018). It is reported that temperature lower than 13 °C and higher than 30 °C affect the growth of plant branches, and temperature between 19 and 23 °C is suitable for tea. The tea plants cannot tolerate water logging; it is very sensitive and cannot survive in the waterlogged area (Parthasarathy et al. 2006; Mukherjee et al. 2017).

Regarding soil nutrients, the percentage of nitrogen content in the soil is considered one of the land suitability factors, as nitrogen is required for plant growth, specifically for the development and production of leaves and stems (Zolekar and Bhagat 2015). As well as soil, organic carbon content is a significant determinant of tea quality

as it is an economic crop generally known for leaves. The soil's carbon content has been reported to benefit branches and leaves growth (Chen et al. 2022).

9.3.3 Detailing on CoCoSo

Combined Compromise Solution (CoCoSo) is a newly developed multi-criteria decision-making model (MCDM) developed by Yazdani et al. (2019). The method combines two MCDMs, namely Weighted Sum Model (WSM) and Weighted Product Model (WPM). Three procedures are used in this strategy to rank the possibilities. The arithmetic means of each alternative score serves as the initial strategy. The scores of each choice are calculated using the second technique and compared to the best ones. Between the first and second strategies, the third one represents a compromise. Utilizing the geometric and mathematical means of the three procedures, the ultimate rank of each possibility is determined (Banihashemi et al. 2021).

The following steps are used to integrate and select the best alternatives.

Step 1: A decision matrix of alternatives (*i*) and criteria (*j*) is prepared as an equation

$$X_{ij} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1e} \\ x_{21} & x_{22} & \cdots & x_{2e} \\ \vdots & \vdots & \ddots & \vdots \\ x_{f1} & x_{f2} & \cdots & x_{fe} \end{bmatrix}, \quad (9.1)$$

$i = 1, 2, 3, \dots, e, j = 1, 2, 3, \dots, f$

Step 2: Raw decision matrix is normalized using equation

For beneficial criteria $r_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}, \quad (9.2)$

For cost criteria $r_{ij} = \frac{\min_i x_{ij} - x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}, \quad (9.3)$

Step 3: Selection of criteria weight is performed using the subjective expert judgment method.

Step 4: Equations are used for performing comparability sequences (Pi) and comparability sequence (Si), respectively.

$$P_i = \prod_{j=1}^n (r_{ij})^{w_j} \quad (9.4)$$

$$S_i = \sum_{j=1}^n (w_j r_{ij}) \quad (9.5)$$

Step 5: Three aggregation approaches are used for measuring the relative weightage.

$$k_{ia} = \frac{S_i + P_i}{\sum_{i=1}^m (P_i + S_i)} \quad (9.6)$$

$$k_{ib} = \frac{S_i}{\min_i S_i} + \frac{P_i}{\min_i P_i} \quad (9.7)$$

$$k_{ic} = \frac{\lambda(S_i) + (1 - \lambda)(P_i)}{\left(\lambda \max_i S_i + (1 - \lambda) \max_i P_i \right)} \quad (9.8)$$

where K_{ia} is the arithmetic mean of sums of scores, K_{ib} is the relative sum of a relative score, K_{ic} is the balanced compromise, and the value λ ranges between 0 and 1, which is free to choose

as decision-maker knowledge. In this study, λ value of 0.5 is taken for the decision solution.

Step 6: Ranking index value of alternatives is calculated as an equation.

$$k_i = (k_{ia}k_{ib}k_{ic})^{\frac{1}{3}} + \frac{1}{3}(k_{ia} + k_{ib} + k_{ic}) \quad (9.9)$$

where K_i represents the conditioning weightage of alternatives, a higher value denotes the best alternatives, and a lower value denotes the worst alternatives.

9.4 Result and Discussion

In the first step, eight conditioning factors have been selected through a literature survey, and a thematic map has been prepared in ArcGIS 10.4. Then, 19,915 random points are selected to extract the raster value (Table 9.2). A decision matrix has been prepared consisting of 19,915 alternatives and eight criteria to make a problem (Table 9.3). The decision matrix has been normalized to get dimensionless values ranging between 0 and 1 (Table 9.4). Furthermore, based on the relationship between conditioning factors and land suitability for tea cultivation, all the criteria are classified into two groups: beneficial and non-beneficial. The criteria having a proportional positive relationship with land suitability are considered beneficial criteria and vice versa. For example, the higher the elevation, the better the suitability for tea cultivation, and it is considered as a beneficial criterion. At the same time, a subjective weighting by three members from the Department of Geography and RM, Mizoram University, assigned weight for conditioning factors as per role as suitable for tea cultivation. The factor of topsoil nitrogen content is credited with the highest weightage, followed by topsoil organic carbon content, distance to a river, elevation, slope, annual average temperature, annual average rainfall, and aspect (Fig. 9.3). In the final stage, Inverse Distance Weightage (IDW) interpolation techniques were implemented to develop spatial land suitability

Table 9.2 Statistical table of investigation factors in tea plantations

Factors	Range	Minimum	Maximum	Mean	SD	Variance	Skewness
Slope	65.400	0.000	65.400	22.565	10.168	103.384	0.186
Elevation	1818.000	25.000	1843.000	652.015	316.145	99,947.440	0.634
Aspect	360.779	- 1.000	359.779	180.943	104.207	10,859.139	- 0.041
Annual rainfall	351.710	2269.900	2621.610	2502.257	50.720	2572.496	- 0.255
Temperature	2.561	20.999	23.559	22.492	0.471	0.222	- 0.533
Distance to river	9085.460	0.000	9085.460	2632.040	1805.176	3,258,660.684	0.512
N_contain	0.240	0.230	0.470	0.360	0.120	0.014	- 0.165
OC_contain	0.580	3.280	3.860	3.594	0.289	0.084	- 0.165

Table 9.3 Decision matrix

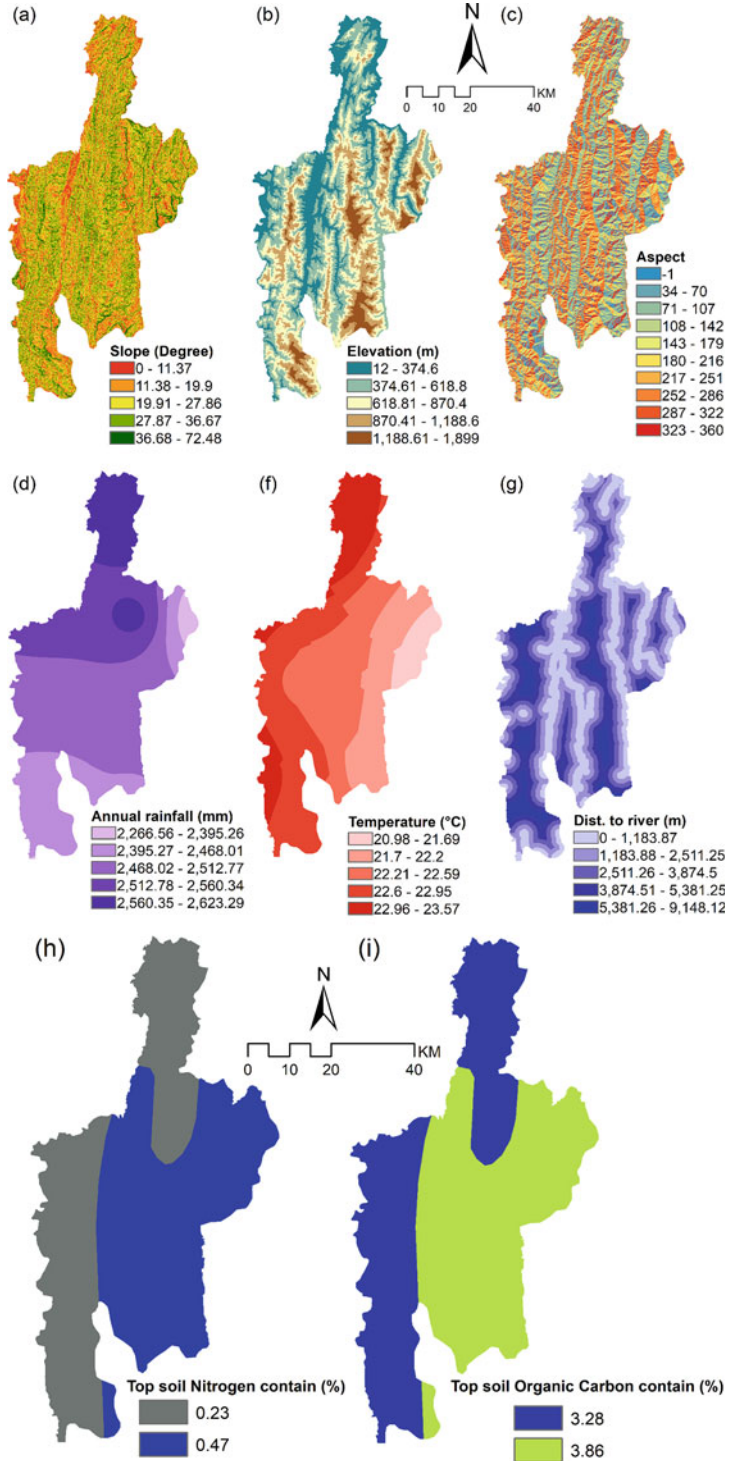
Alternatives	Criteria							
	Slope	Elevation	Aspect	Annual rainfall	Temperature	Dist. to river	N_contain	OC_contain
	10.50	25.00	159	2609.270	22.989	0.000	0.230	3.280
	11.43	30.00	78	2593.900	22.872	239.008	0.230	3.280
	24.37	35.00	57	2606.060	22.914	0.000	0.230	3.280
	0.00	36.00	- 1	2593.700	22.871	0.000	0.230	3.280
	0.00	37.00	- 1	2591.490	22.869	0.000	0.230	3.280

	38.179	1821.000	54.392	2502.830	22.295	3250.860	0.470	3.860
	26.562	1823.000	52.374	2509.250	22.369	6980.520	0.470	3.860
	5.957	1825.000	198.435	2505.450	22.359	5392.270	0.230	3.280
	13.232	1835.000	201.615	2466.130	22.015	5640.800	0.470	3.860
	22.169	1843.000	68.629	2466.230	22.019	5241.860	0.470	3.860

Table 9.4 Normalized decision matrix

Slope	Elevation	Aspect	Annual rainfall	Temperature	Dist. to river	N_contain	OC_contain
0.16	0.00	0.44	0.96	0.78	1.00	0.00	0.00
0.17	0.00	0.22	0.92	0.73	0.97	0.00	0.00
0.37	0.01	0.16	0.96	0.75	1.00	0.00	0.00
0.00	0.01	0.00	0.92	0.73	1.00	0.00	0.00
0.00	0.01	0.00	0.91	0.73	1.00	0.00	0.00
...						
0.58	0.99	0.15	0.66	0.51	0.64	1.00	1.00
0.41	0.99	0.15	0.68	0.54	0.23	1.00	1.00
0.09	0.99	0.55	0.67	0.53	0.41	0.00	0.00
0.20	1.00	0.56	0.56	0.40	0.38	1.00	1.00
0.34	1.00	0.19	0.56	0.40	0.42	1.00	1.00

Fig. 9.2 Conditioning factors for land suitability: **a** slope, **b** elevation, **c** aspect, **d** annual rainfall, **e** temperature, **g** distance to river, **h** topsoil nitrogen content, and **i** topsoil organic carbon content



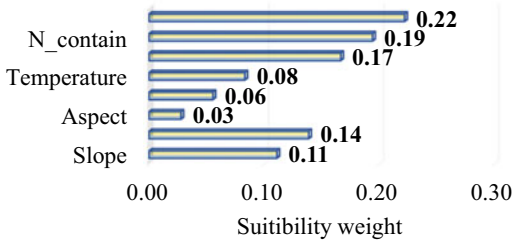


Fig. 9.3 Suitability weight assigned to the conditioning factors

based on K_{ia} , K_{ib} , K_{ic} , and K_i value (Fig. 9.2 and Table 9.5).

As per suitability level, the area has been classified into five suitability classes, like very high suitability area, high suitability area, moderate suitability area, low suitability area, and very low suitability area (Fig. 9.4). Very high suitability areas are found in moderate slope and elevation along the roads of the study area covering 23.74% of the area. Similarly, high suitability area has been found buffering the very susceptibility areas covering areal extension 34.89% forwarded by moderate suitability areas (26.34%), low suitability areas (12.05%), and

very low suitability areas (2.98%) (Tables 9.5 and 9.6).

9.4.1 Very High Suitability Zone

The slope of the district ranges between 0° and 72.48° and is diverse in nature. A low slope is found at the valley, and a steep slope is near the hilltop. The very high suitability area belongs to a slope range between 19° and 27°, similar to that in Yingde city in Guangdong provinces, China (Chen et al. 2022). Table 9.7 shows that in the suitability areas, the elevation value ranges between 14 and 1840 m, with an average value of 680 m. In case of the aspect factor, the southeast facing slope is more suitable than other slope-facing areas.

The area’s annual rainfall ranges between 2266 and 2623 mm, whereas the very high suitability zone is found where the rainfall average is 2471.7 mm with an average temperature of 22.43 °C. While considering the distance to a river, between 3000 and 4000 m from a river course is highly suitable for tea cultivation. The

Table 9.5 Values of alternative used for interpolation

Latitude	Longitude	Mia	Mib	Mic	Mi
24.38541956230	93.02001609810	2.98781E-05	370.304	0.18768	123.625
24.34050009330	93.03946354440	2.85034E-05	1058.47	0.18071	353.06
24.24046704220	93.01083314370	3.11773E-05	698.984	0.19466	233.221
24.33797902130	93.03934096410	2.66563E-05	3239.64	0.17184	1080.18
24.19829076160	93.00159515250	2.66274E-05	3302.1	0.17171	1101.01
...					...
23.80106352250	92.94626228340	7.67245E-05	28.1397	0.43453	9.62267
23.85143655230	92.93133995280	6.86926E-05	67.2562	0.3922	22.6714
23.83059849870	92.93353552340	2.96358E-05	514.687	0.18646	171.766
23.51487410580	92.97713261540	6.83109E-05	38.7269	0.39018	13.1401
23.52111306630	92.97506832520	6.95475E-05	90.3769	0.39672	30.3935

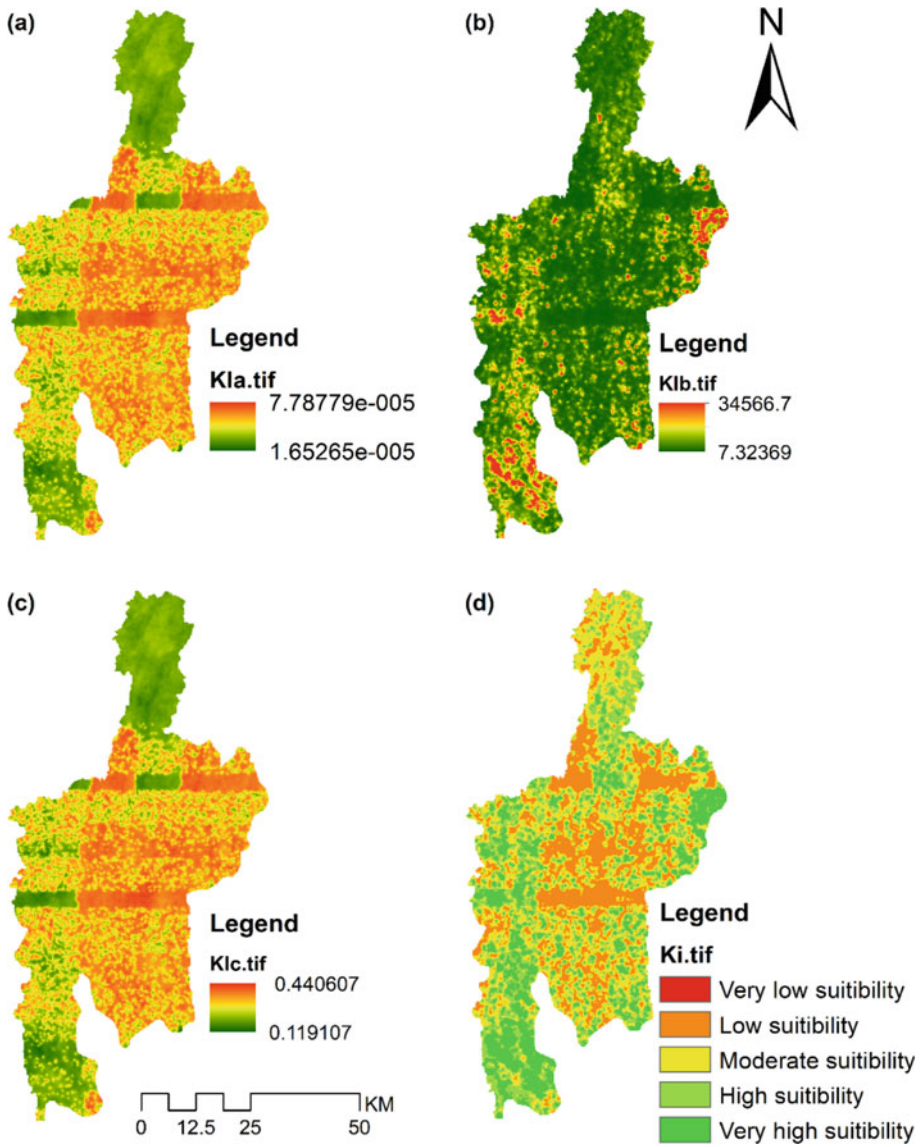


Fig. 9.4 Relative weight, **a** Kia, **b** Kib, **c** Kic, and **d** land suitability zones for tea cultivation

Table 9.6 Areal extension of different suitability class

Suitability classes	Mi class	Area	Area (%)
Very high	4.1–4.3	819.158	23.74
High	4.4–4.4	1203.87	34.89
Moderate	4.5–4.6	908.864	26.34
Low	4.7–4.8	415.727	12.05
Very low	4.9–5.6	102.768	2.98

Table 9.7 Statistical table of investigation factors in tea plantations in very high suitability class

Factors	Min	Max	Mean	SD
Slope	0	71.8545	21.4596	10.044414
Elevation	14	1840	680.142	307.707083
Aspect	- 1	359.799	142.346	104.360116
Annual rainfall	2266.56	2617.88	2471.7	52.527717
Temperature	20.9904	23.5453	22.4355	0.520793
Dist. to river	0	8881.98	3264.79	2021.553544
N_contain	0.23	0.47	0.3249	0.117345
OC_contain	3.28	3.86	3.50933	0.283583

Table 9.8 Statistical table of investigation factors in tea plantations in high suitability class

Factors	Min	Max	Mean	STD
Slope	0	70.5298	22.4567	10.149155
Elevation	16	1898	625.798	303.80085
Aspect	- 1	359.825	165.273	100.304778
Annual rainfall	2271.62	2622.84	2502.13	52.934739
Temperature	21.0185	23.5537	22.5363	0.447531
Dist. to river	0	9148.12	2768.66	1855.54515
N_contain	0.23	0.47	0.32509	0.117387
OC_contain	3.28	3.86	3.50981	0.283684

very high suitability classes are found with high soil nutrient areas for soil factors.

9.4.2 High Suitability Zone

Table 9.8 shows high suitability zone is located at places with an average slope of 22.45° and an average elevation of 625 m. In case of the aspect factor, south facing slopes dominate in this zone. The annual rainfall of this zone is quite higher than very high suitability zones at about 2502.13 mm. With respect to the distance factor, the area between 2000 and 3000 m is mainly affected by soil erosions.

Similar to very high suitability zone, the amount of soil nutrients is also found high in high suitability zones. Here in the study, the moderate, low, and very low suitability classes are considered non-profitable for tea cultivation.

9.5 Validation of the Study Outcome

Initially, the kappa statistics were implemented in the psychological test to compare two independent responses (Cohen 1960). Since then, various fields, including modeling, and mapping, have used the kappa statistic. In the chapter, we applied kappa statistics to compare land suitability zones with *Jhum* land in the study area. The kappa statistics were based on a confusion matrix of two maps, i.e., land suitability and *Jhum* map, using Fig. 9.5.

All the processes have been done using the SCP plugin in QGIS 3.10.7 environment. Here, we used existing farmland that local people used and classified it into five classes according to area extension and production. As a result, the overall accuracy for the present study is 87.27%, representing almost perfect classification.

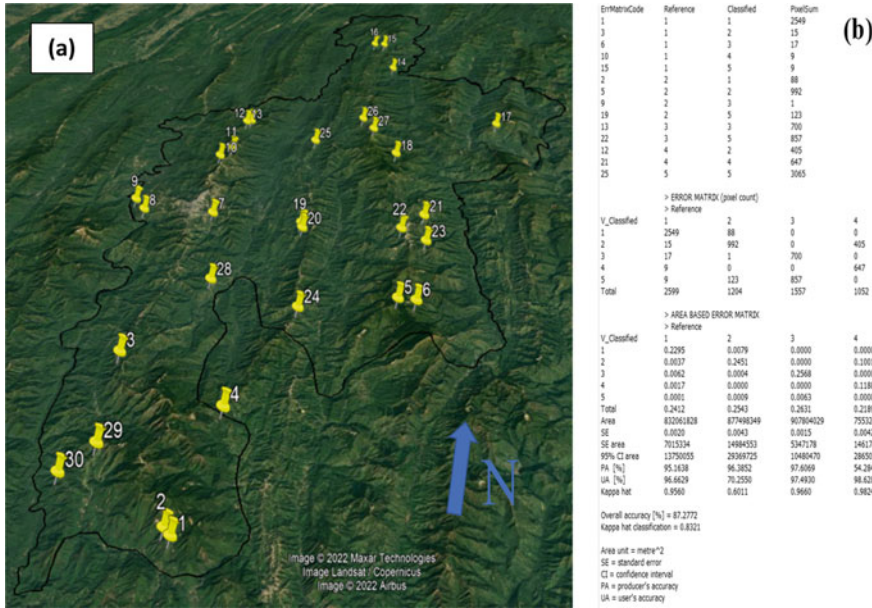


Fig. 9.5 a location of sample *Jhum* land used for validation, b Kappa matrix has done SCP plugin in QGIS environment

9.6 Conclusions

The district is dominated by Mizo people who have been practicing *Jhum* since historical times and get very little production from such cultivation. The current study is focused on identifying suitable lands for tea cultivation in the Aizawl district of Mizoram. Different environmental criteria, namely elevation, slope, aspect, long-term average rainfall, annual temperature, distance to a river, soil nitrogen content, and soil organic carbon content, are evaluated using CoCoSo MCDM with the help of subjective weights of criteria. Soil nitrogen content is credited the highest weightage, and aspect is credited the lowest weightage. The final integration has been done in the GIS environment. As per the alternative ranking, the area has been classified into five land suitability zones: very high, high, moderate, low, and very low suitability. The overall result shows that 23.74% of the total areas are highly suitable for tea cultivation. Although there is the unavailability of all the thematic layers in a digital format required for land suitability analysis, the present study will

help government agencies to restart tea cultivation in the study area.

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