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Multi-criteria evaluation for citrus fruits land use suitability using AHP technique in Churachandpur district, Manipur

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Abstract

Analytic Hierarchy Process (AHP) has emerged as one of the most important structured technique in the field of complex decision analysis. In this paper, an endeavour has been made using AHP for land use suitability of citrus fruit production. The study is not necessarily optimal solution to a given model in the area under consideration. Using Saaty's nine-point scale for pair wise comparisons, one may be able to precisely measure the 'goodness' of the approximation. In the present envisaged study, the factors like slope, road proximity, soil depth, absolute relief and soil pH affecting in the process are analytically and logically encompassed to make a gainful research through a scientifically proven method, which has been depicted in this present paper in a sequential manner.

Key words*:* Analytical Hierarchy Process (AHP), Multi-Criteria Evaluation (MCE), suitability.

Introduction

Land suitability evaluation and agricultural land use planning are very necessary and are the basic information for right decision making afterward (FAO,1993). In order to achieve high yield and high quality of fruit trees, it is very important to select the appropriate farming system (Dixon et al., 2001) and to estimate the suitable land for certain crops (Huynh & Boehme, 2005; Huynh et al., 2006).

Land use suitability is the ability of a given type of land to support a defined used. The process of land suitability analysis involved evaluation and grouping of areas of land in terms of their suitability for a defined purpose. The main object of land suitability evaluation is the prediction of potential capacity of the land unit for the given use without deterioration (De La Rosa and Van Diepen, 2002). Land evaluation can be carried out on the basis of biophysical parameters and/or socio-economic conditions of an area (FAO, 1976). Biophysical factors tend to remain stable, unlike socio-economic factors that are affected by social, economic and political settings (Dent and Young, 1981; Triantafilis et al., 2001). Thus, physical land suitability evaluation is a prerequisite for land use planning, because it guides decisions on optimal utilization of land resources (Van Ranst et al., 1996). The principles of sustainable development make land-use suitability analysis become increasingly complex due to consideration of different requirements/criteria. It includes consideration not only inherent capacity of a land unit to support a specific land use for a long period of time without deteriorating, but also the socio-economic and environmental costs. Research in this area is very important to achieve cost effective and sustainable development of land use in general and specific land use planning in particular.

In many situations, it is extremely difficult to assign relative weights to the different criteria involved in making a decision on suitability of land mapping unit for a land use type. Therefore, it is necessary to adopt a technique that allows an estimation of the weights. One such technique is Analytical Hierarchical Process (AHP).

Study area

Churachandpur district covers an area of 4775 sq. km. It is located between 24^{o}N to 24^{o}3'N latitude and 93^{o}15'E to 94^{o}0'E longitude in the south-western part of Manipur (Fig. 1). The region has undulating topography whose border is demarcated by Barak River in the west, Manipur River in the east, and Tuivai and its tributaries in the south and tributaries of Barak in the north. There are 15 drainage sub-basins in the area of which major tributaries are Tuitha Lui (Khuga), Tuivai Lui and Tuiruong (Barak) Lui. Altitude ranges from 110m to 1915m above mean sea level. The soil varies from red laterite in the hills and alluvial soils in the valley. Monsoon climate dominates the region. The region receives rainfall mainly from south-west monsoon, ranging between 1000mm to 2900mm. The western part of the district receives less rainfall compare to the eastern and northern part. Humidity ranges from 70% to 86%. The total population of the district according to 2011 census is 2, 71,274 persons.

Objective

The main objective of the study is to apply AHP technique to determine land use suitability for citrus fruits viz. lemon, orange and lime.

Data base and methodology

Survey of India toposheets on 1:250,000 scale bearing No. 83H and 84E has been used to prepare the base map. Slope, road proximity, aspect, absolute relief and soil pH maps are prepared from the base map.

The research process consists of various components of research methodology. Each component plays an important role in finding suitable land for various crops in the hills. Keeping in mind the goal and objectives, the first component focuses establishing set of criteria or attribute. The second is to assign ranks to the criteria and alternatives. A pair-wise comparison matrix is carried out to get relative weights. Then gathered weights were computed keeping in view consistency ratio (CR). If CR is satisfactory, the computed weights will be recorded for further processing. The flow chart showing the steps of multi-criteria evaluation of land suitability analysis is given in figure 2.

The methodology of Analytical Hierarchical Process (AHP) used in the multi-criteria evaluation of land use suitability is shown in details in figure 3.

Results and Discussion

1. Evaluating criteria

The geo-environmental condition of Churachandpur district is favourable for the growth of citrus fruit at commercial scale. However, it is planted in limited scale for home consumption only. The effective criteria in land use suitability analysis for citrus fruits are briefly given below along with their individual importance.

1. (a) Slope

Slope is an important criterion for hilly terrain for finding suitable sites for various crops. Steep slopes are disadvantageous due to its increase erosive power and not easily accessible for any farming activities. On level surface, soil is deepest, soil erosion is little or nil and drainage is poor. In case of high rainfall, level ground may tend to have swampy region. Gentle slopes may have soils of fair depth; drainage is to the extent to avoid swampiness or water logging. If climatic conditions are favourable, gentle slopes are likely to have maximum production. Steep and very steep slopes do not support deep soils. Soil erosion problems are severe. They may have exposed rocks. Tree growth is not good but occurs scattered in patches where better soil exist.

1. (b) Road proximity/accessibility

For economic development of any region accessibility plays an important key role. Easy access to road helps in movement and transportation at any place. However, the construction of new road is expensive in any hilly regions. So any site located nearer to the existing road is more advantage than far away from the existing road. Bhat et al., (2000) defined 'accessibility is a measure of the ease of an individual to pursue an activity of a desired type, at a desired location, by a desired mode, and at a desired time'. This definition shows that any kind of activity cannot be generated without sustainable accessibility. For sustainable accessibility, prior steps should be taken like land suitability analysis using multi-criteria decision analysis approach. It can enhance economic activities from source to destination.

1. (c) Soil depth

Soil depth is useful for understanding the depth to foothold. Soils in valleys are deeper, richer and more productive in the valley and depression than soils on the slopes and ridges in the upslopes or hills.

1. (d) Absolute relief/altitude

Altitude modifies the local climate of a place. With increase in altitude, temperature decreases. So, any area having high absolute relief will have sub-tropical type of climate in the study area. Wind velocity increases with altitude upto certain altitude and then it is almost constant. The slopes of the ridges are usually protected from high velocity winds but the top ridges and high mountain ranges face high velocity winds, which create mechanical injury and obstruction in plant growth. At higher altitudes, temperature is low and chemical and biochemical processes of weathering, decomposition of litter, etc. are considerably slow. Thick layer of organic matter accumulates on the soil surface. Soil temperature remains low making plant growth difficult.

1. (e) Soil pH

Soil pH is most useful in land suitability evaluation and management as it provides information about the solubility and thus potential availability or phyto-toxicity of elements for crops subsequently the soil suitability for specific crops. Highly acidic and alkaline soils do not favour any crop production.

2. Framework of land suitability evaluation

In order to obtain the importance of evaluating criteria and weightings the AHP technique is used. It has been widely used as a multi-criteria evaluation approach. It is a rational decision making approach which simplifies complicated problems and breaks down into smaller parts into hierarchical structuring (Saaty, 2008).

There are three principles of AHP, i.e.,
1) Hierarchical Structuring
2) Weighing, and
3) Logical consistency

Saaty developed the following ladder in 1980 for applying the AHP:

1. To state the problem.
2. To design hierarchy structure of the problem of various levels including goal, criteria, sub-criteria and alternatives keeping in view determining objectives and its outcome.
3. To compare each element in the corresponding level and calibrated them on the numerical pair-wise comparison scale. Elements of a problem are compared in pairs with respect to their relative impact (weight or intensity) on a property they share in common. Element matrix has reciprocal properties: aij=1/aij
4. To perform computations to find the maximum Eigen value, consistency index CI, consistency ratio CR, and normalized values for each criterion.
5. If there is any matrix with an unaccepted for CR value or composite weight i.e. >0.10, the expert is required to make judgment on that matrix repeatedly till these values lie in a desire level.

It helps in determining a suitable location for certain crops on the hilly regions. The process of AHP for solving problem is structured the decision problem in a hierarchical model establishing suitability criteria or attribute for different types of crops.

A. Computation of pair-wise comparison matrix and consistency

Pair-wise comparison matrix is created to assign weights. Weights are evaluated to find alternatives and estimating associated absolute numbers from 1 to 9 in fundamental scale of the AHP presented in table 1.

Applying Saaty's nine point weighing scale, the relative importance of each criteria have been made for pair wise comparison matrix (Table 1). Each criteria has been given weights and score values (Table 2).

B. Estimation of consistency ratio

In order to prevent bias thought in criteria weighing, consistency ratio is being calculated. To calculate the entire pair-wise comparison matrix to find the maximum Eigen value (λ_{max}), Consistency Index (CI), the value for Eigen value is simply the average value of consistency vector. To calculate the consistency index, CI is given by: CI= (λ_{max}-n)/n-1.

For each level in the hierarchy it is necessary to know whether the pair-wise comparison matrix has been consistent in order to accept the results of the weighing. The parameter that is used to check is called consistency ratio. The consistency ratio is a measure of how much variation is allowed and much less than 10%. RI is the average random consistency index is shown in table 3. Therefore, judgment consistency can be checked taking the consistency ratio, CR= CI/RI. If CR is satisfactory, it does not exceed from desired range i.e. >0.10. If CR value is undesired range, the obtained judgment matrix is needed to review till these values should be improved and satisfactory. In the present model consistency ratio is less than 0.10. This indicates that comparisons of criteria are perfectly consistent or within acceptable range of consistency, and the relative weights are suitable for use in the suitability analysis.

The consistency ratio for each criteria for citrus (sub-tropical) fruits is less than or equal to 0.01 consistency level. The CR value for slope is 0.08, road proximity -0.01, soil depth is 0.13, absolute relief is 0.03 and soil pH is -0.03 (Table 6).

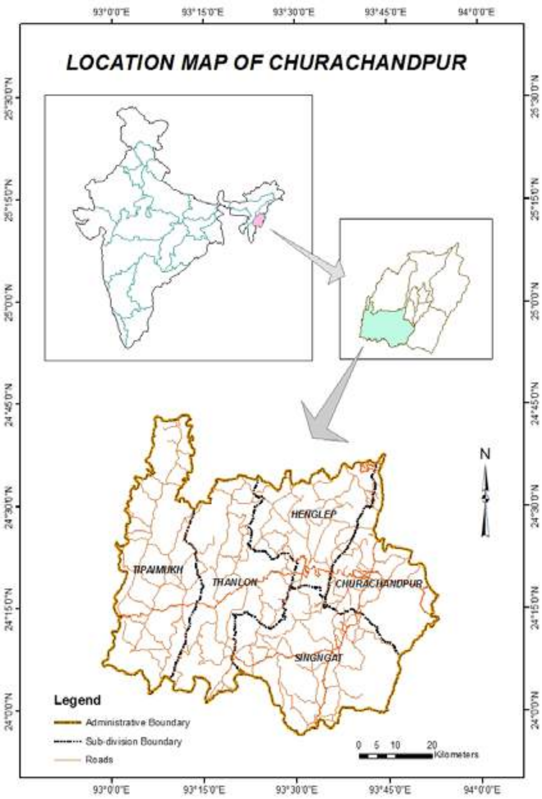

Fig. 1. Study area

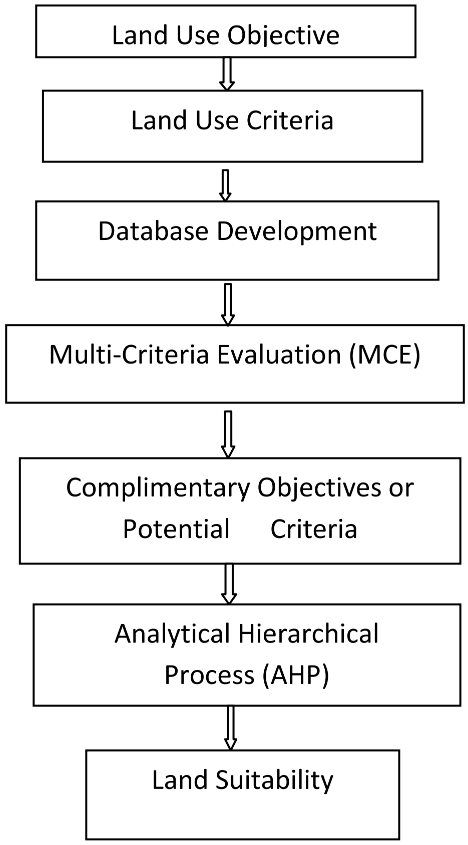

Fig. 2. Flow chart of Land Suitability Analysis.

Development of hierarchy structure

↓

Weighted of each element in the hierarchy

↓

Assign the score to each class

↓

Pair wise comparison matrix (CR<0.1)

↓

Overlaying (Weighted sum)

↓

Final Suitability Map

Fig. 3. Methodology of Analytical Hierarchical Process and integration of map layers.

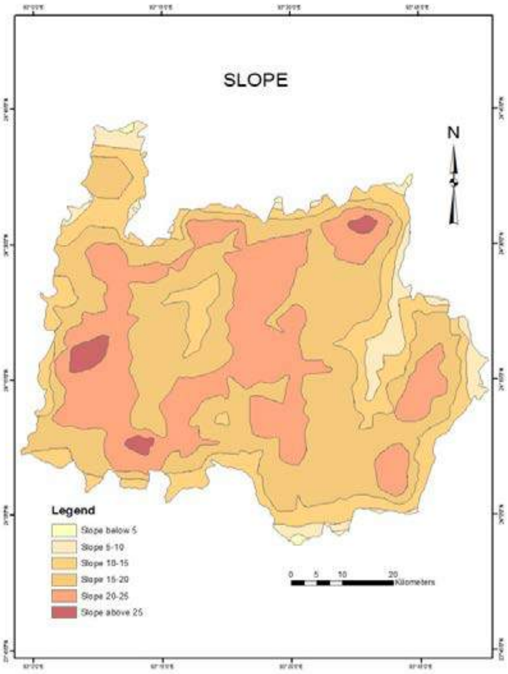

Fig. 4. Spatial distribution of slope map

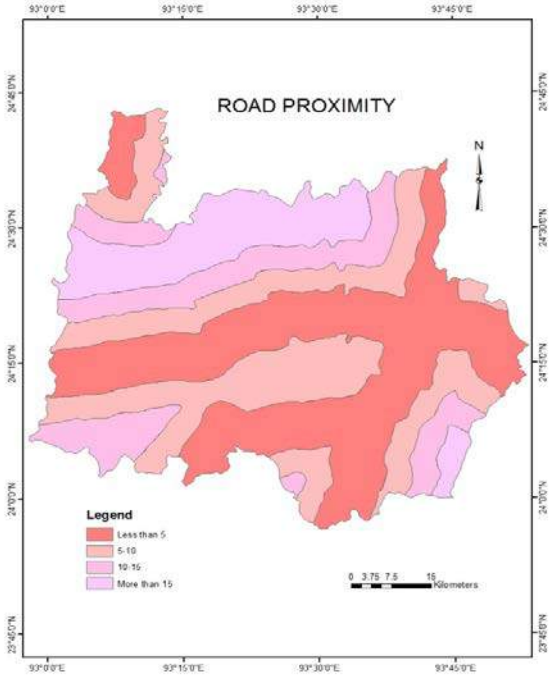

Fig. 5. Spatial distribution of road proximity

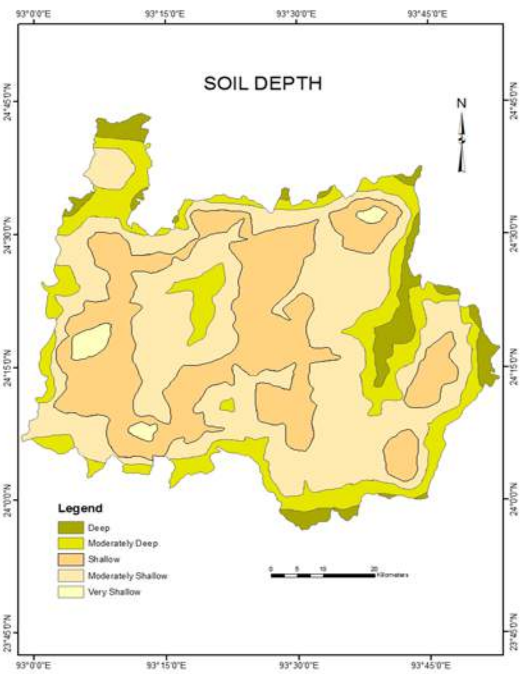

Fig. 6. Spatial distribution of soil depth

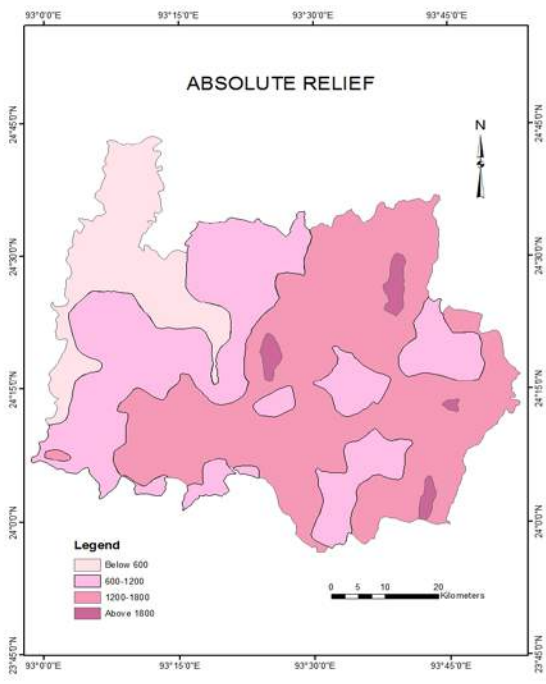

Fig. 7. Spatial distribution of absolute relief

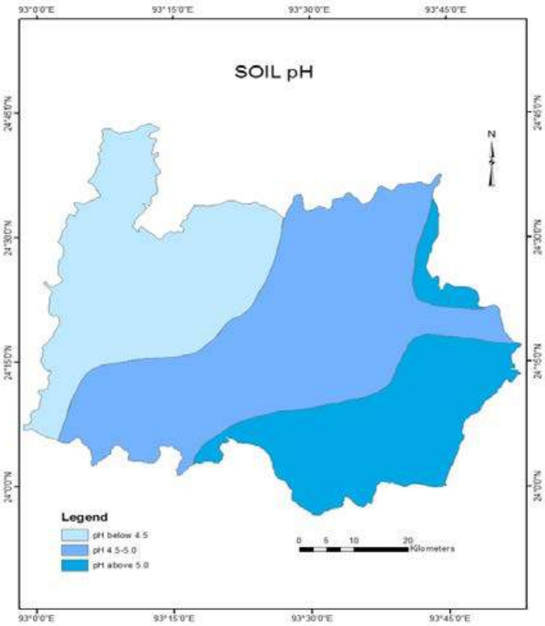

Fig. 8. Spatial distribution of soil pH

Fig. 9. Plantation of lemon along with tree bean and banana near Mata.

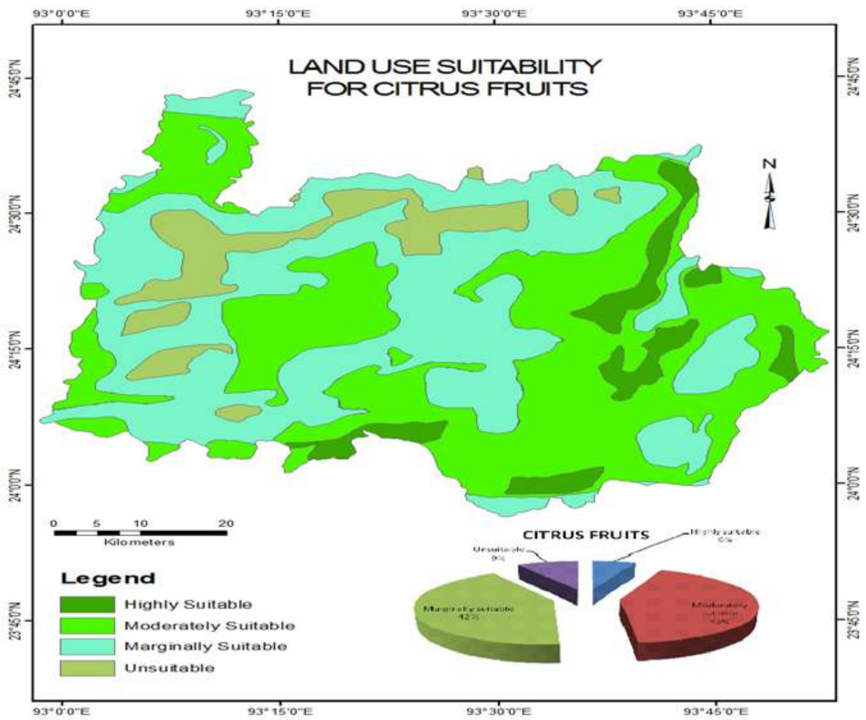

Fig. 10. Final land use suitability map and pie diagram for citrus fruits.

Table 1. Nine-point weighing scale for pair-wise comparison.

Description	Scale
Equally preferred	1
Equally to moderately	2
Moderately preferred	3
Moderately to strongly	4
Strongly preferred	5
Strongly to very strongly	6
Very strongly preferred	7
Very strongly to extremely	8
Extremely preferred	9
Source: (Saaty, 1980)	

Table 2. Weights of criteria in land-use suitability analysis for citrus fruits.

Criteria	Weightage (%) (wi)	Attribute values of criteria	Score (xi)
Slope	0.30 (30)	<5	2
		5-10	4
		10-15	8
		15-20	6
		20-25	3
		>25	1
Road proximity	0.25 (25)	<5	8
		5-10	6
		10-15	3
		>15	1
Soil depth	0.20 (20)	Deep	3
		Moderately deep	8
		Shallow	6
		Moderately shallow	3
		Very shallow	1
Absolute relief	0.15 (15)	<600	2
		600-1200	3
		1200-1800	5
		>1800	7
Soil pH	0.10(10)	<4.5	1
		4.5-5.0	3
		>5.0	6

Table 3. Average Random Consistency Index (RI).

Size of matrix	1	2	3	4	5	6	7	8	9	10
Random index	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 4. Comparison matrix and weights related to slope.

Slope	Pair wise comparison matrix						Normalized pair wise comparison matrix						Criterion weights
	a	b	c	d	e	f	a	b	c	d	e	F	(a+b+c+ d+e+f)/6
>25 (a)	1	3	6	8	4	2	0.42	0.61	0.56	0.43	0.17	0.08	0.37
20-25 (b)	0.33	1	3	6	8	4	0.13	0.20	0.28	0.32	0.35	0.16	0.24
15-20 (c)	0.16	0.33	1	3	6	8	0.06	0.06	0.09	0.16	0.26	0.33	0.16
10-15 (d)	0.12	0.16	0.33	1	3	6	0.05	0.03	0.03	0.05	0.13	0.25	0.09
5-10 (e)	0.25	0.12	0.16	0.33	1	3	0.10	0.02	0.02	0.01	0.04	0.12	0.05
<5 (f)	0.50	0.25	0.12	0.16	0.33	1	0.21	0.05	0.01	0.01	0.01	0.04	0.05
Total	2.36	4.86	10.70	18.58	22.33	24							

Table 5. Computation of consistency vector.

Slope	Weighted sum vector	Consistency vector
>25 (a)	1(0.37)+3(0.24)+6(0.16)+8(0.09)+4(0.05)+2(0.05)=3.07	3.07/0.37=8.29
20-25 (b)	0.33(0.37)+1(0.24)+3(0.16)+6(0.09)+8(0.05)+4(0.05)=1.98	1.98/0.24=8.25
15-20 (c)	0.16(0.37)+0.33(0.24)+1(0.16)+3(0.09)+6(0.05)+8(0.05)=1.25	1.25/0.16=7.81
10-15 (d)	0.12(0.37)+0.16(0.24)+0.33(0.16)+1(0.09)+3(0.05)+6(0.05)=0.66	0.66/0.09=7.33
5-10 (e)	0.25(0.37)+0.12(0.24)+0.16(0.16)+0.33(0.09)+1(0.05)+3(0.5)=0.35	0.35/0.0.05=7.00
<5 (f)	0.5(0.37)+0.25(0.24)+0.12(0.16)+0.16(0.09)+0.33(0.05)+1(0.05)=0.32	0.32/0.05=6.40

Table 6. Parameters of analytical hierarchical process (AHP).

Parameter	Slope	Road proximity	Soil depth	Absolute relief	Soil pH
Eigen value (λmax)	7.51	3.97	5.61	4.01	2.96
N	6.00	4.00	5.00	4.00	3.00
Consistency Index (CI)	0.10	-0.01	0.15	0.00	-0.02
Random Index (RI)	1.24	0.90	1.12	0.90	0.58
Consistency Ratio (CR)	0.08	-0.01	0.13	0.03	-0.03

Table 7. Land use suitability for citrus fruits.

Class	Area (km^2)	Percentage (%)
Highly suitable	296.14	6.20
Moderately suitable	2035.21	42.62
Marginally suitable	2023.56	42.38
Unsuitable	420.09	8.80
Total	4775.00	100

So, the AHP analysis is accepted for further processing. The criteria maps are prepared using weighted linear combination method to produce map layers for each criterion. Each map layers are overlay to produce the final land use suitability map for citrus fruits (Fig. 10).

Suitability map resulting from multi-criteria evaluation have shown different classes for which the degree of suitability vary from highly suitable to unsuitable. Based on relative weights of suitability factors, suitability ranges are identified. Figure 10 depicts the final land use suitability map for citrus which divides the study area into four suitability classes shown in different colours. From table 7 and figure 10, it could be generated that highly suitable land for citrus fruit covers only 6.20% spatially distributed in the north-east and southern part of the study area. Moderately suitable land occupies 42.62 % concentrating mainly in the eastern part, marginally suitable land occupies 42.38% concentrating from the central towards the western part of Churachandpur district. Unsuitable land for citrus plantation covers 8.80 % in pocket area in the north and western part of the entire study area.

Conclusion

The analysis of this study mainly focused on highly suitable areas as these areas have highest potential for citrus plantation. AHP model has been to land use suitability analysis based on five criteria layers. The Analytic Hierarchy Process (AHP) method has been found as a useful method to determine the weights, as compare to other methods used for determining weights. The sensitivity utility of this model helped to analyze the decision before making the final choice. The AHP method could deal with inconsistent judgments and can provide a tool to measure the inconsistency of the judgment taken by the respondents. This assessment can be useful in decision-making process for land use planning and can also help in sustainable land use in the area. It is very important for planners to decide whether land should be developed immediately or to be conserved for future development. This model can help to prepare the strategic agricultural development framework and the short-term land use policies can be formulated. The approach, therefore, can help the planners and policy makers to monitor agricultural land development for formulating sustainable development in hilly region.

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