

Site-suitability analysis for turmeric in Jaintia Hills of Meghalaya, India, using analytical hierarchical process and weighted overlay analysis: a comparative approach

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India is the largest producer, consumer and exporter of turmeric (*Curcuma longa* L.). The Lakadong variety of turmeric is endemic to Jaintia Hills of Meghalaya, India. It is considered as the best quality turmeric containing 7.5% curcumin, which is about three times higher than the other varieties (2–3%). This study identifies potential sites for turmeric cultivation in Jaintia Hills using geospatial techniques, viz. analytical hierarchical process (AHP) and weighted overlay analysis (WOA). WOA identified a total of 162,263.70 ha suitable for the expansion of Lakadong variety of turmeric in Jaintia Hills, of which 18% was highly suitable, 31% moderately suitable and 32% was marginally suitable. In the case of AHP, 21% area was found to be highly suitable, 25% moderately suitable and 45% marginally suitable.

Keywords: Analytical hierarchical process, site suitability analysis, turmeric, weighted overlay analysis.

OVER the years, horticulture has emerged as one of the potential agricultural enterprises in accelerating the growth of economy in India. Its role in the country's nutritional security, poverty alleviation and employment generation programmes is becoming increasingly important. The agro-climatic conditions of Meghalaya, India, provide excellent condition for growing different horticultural crops, including fruits, vegetables, spices, plantation crops, and medicinal and aromatic plants of high economic value. Turmeric (*Curcuma longa* L.) has been used in India as a spice as well as in medicine since time immemorial. Turmeric (family: Zingiberaceae) is used as a condiment, drug, dye, cosmetic, and also in religious ceremonies¹. India is the largest producer and exporter of turmeric in the world. Turmeric occupies nearly 1.55 million hectares (m ha) (which is 6% of the total area under spices) in the country with average productivity of 3533 kg/ha (ref. 2). It can be grown with little care, and can turn a barren land or wasteland into

productive land with a less effort, thus improving the rural livelihood³.

Lakadong, the local variety of turmeric is grown in Jaintia Hills, Meghalaya, India. This variety is indigenous to the Shangpong area of Jaintia Hills and is considered as the best quality turmeric with curcumin content as high as 7.5% (refs 4–6). The variety has high market value; however, it has low-yield potential because of diseases like leaf spot and leaf blotch which limit its further expansion. The Indian Council of Agricultural Research (ICAR) Research Complex of the North Eastern Hill Region has developed a promising turmeric variety known as Megha Turmeric-1 to overcome these problems⁶.

The turmeric varieties having export potential can be expanded to other suitable areas for increasing the area under production. Suitable areas for growing turmeric can be assessed using the recent multi criteria decision making (MCDM) systems such as analytical hierarchical process (AHP) and weighted overlay analysis (WOA). Development of MCDM approaches took place during the 1960s to integrate numeral options, varied opinions into a potential new framework. AHP as a decision support system has gained popularity due to its ability to handle large amounts of heterogeneous data^{7,8}. The ranks in AHP are generally judged by expert opinion. The consistency is assessed with the help of consistency ratio (CR)^{9,10}. Again, WOA is a similar kind of approach, however, it lacks the ability to check consistency, and both the rank and weight are judged using expert opinion, which again in many stages can result in a bias, or the opinion may vary from one expert to another.

Study area

Jaintia Hills has a total geographical area (TGA) of 3819 sq. km (Figure 1). The geographical extent of the Jaintia Hills district is between 25°01'16.11"–25°45'06.42"N lat. and 92°48'35.09"–91°58'29.24"E long. The elevation ranges from 76 m (at Dawki) to 1627 m (at Maryngksi). The soils of the Hills are dark brown to dark reddish-brown

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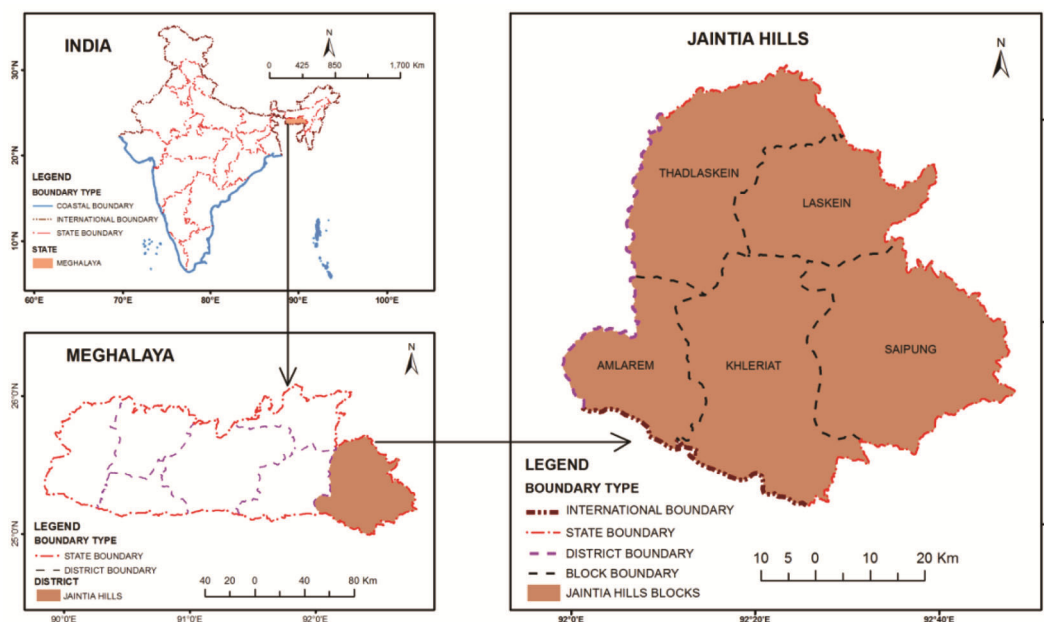


Figure 1. Map of the study area (Jaintia Hills, Meghalaya, India).

in colour, varying in depth from 50 to 200 cm. The texture of soils varies from loamy to fine loamy¹¹.

Materials and methods

Two satellite imageries (111/54 for 26 October 2015 and 18 March 2016) of Resourcesat-2 Linear Imaging Self Scanning Sensor-III (LISS-III) were utilized for delineation of major land-use land-cover (LULC) classes with on-screen digitization through visual image interpretation techniques using ArcGIS 10.2 software. Eight major LULC classes were identified in Jaintia Hills, viz. agricultural lands (AL), built-up lands (BUL), forest lands (FL), forest-tree-clad area–open (FTCAO), shifting cultivation–current (SCC), shifting cultivation–abandoned (SCA), wastelands (WL) and water bodies (WB). FTCAO, SCC and SCA were considered for the identification of potential sites for turmeric cultivation. In this context, only three classes have been considered because other land-use scenarios like many agricultural plots have been permanently dedicated for major agricultural crops and several land-cover classes, viz. water, reserve forest areas have been transformed into settlement, roads, industries and other developmental purposes; hence they cannot be easily transformed for the cultivation of turmeric. Accuracy assessment for LULC was carried out using standard methods¹².

Soil maps on 1 : 50,000 scale (50 K) prepared by the North Eastern Space Applications Centre, Meghalaya in collaboration with Soil and Land Use Survey of India (SLUSI), New Delhi were used for extracting the required soil parameters, viz. texture, erosion, depth, soil drainage, pH, available P₂O₅ available K₂O, etc. Land

capability classes (LCCs) were interpreted from the soil 50 K map following standard criteria¹³ (Table 1). All soil parameters were grouped into four classes of suitability, viz. highly suitable, moderately suitable, marginally suitable and not suitable based on suitability criteria¹⁴.

Digital elevation model (DEM) 10 m data generated from Cartosat-1 satellite imagery were used for the extraction of physiographic parameters, viz. elevation, slope and aspect using ArcGIS 10.2 software. Automatic weather station (AWS) data of four stations (Amlarem – ISRO0048_15F030, Jowai – ISRO0042_15F02A, Kalline – ISRO1067_15F42B and Kkeirihat – ISRO0043_15F02B) were utilized for generating spatial database of climatic parameters, viz. average annual rainfall and mean temperature using interpolation technique in ArcGIS 10.2. Kriging method was used to interpolate the climatic data because in this method low value within the optional output variance of prediction raster indicates a high degree of confidence in the predicted value. It is more rational than any other traditional methods used for interpolation. Further, kriging estimates are known to be unbiased and have minimum variance¹⁵. The rainfall and temperature data were grouped into four classes of suitability, viz. highly suitable, moderately suitable, marginally suitable and not suitable based on suitability criteria for turmeric crop¹⁴ (Table 2).

Criteria adopted for site selection

The GIS database pertaining to soil, slope, aspect, elevation and climatic parameters was categorized into four classes according to the level of suitability, i.e. high, moderate, marginal and not suitable following standard

Table 1. Criteria for land capability classification¹³

Land capability class	Soil texture	Soil erosion	Soil depth (cm)	Permeability	Slope (%)	Distance from active gully head
I	Silty clay loam, clay loam, loam, silt loam	Slight	100	Moderate	0–1	More than 60 m
II	Silty clay loam, silt loam	Moderate	50–100	Moderately slow	1–5	Minimum 60 m
III	Loamy sand, sand, silty clay	Severe	25–50	Slow and rapid	3–10	Between 6 and 60 m
IV	Clay	Severe	10–25	Very slow	10–33	–
V	Same characteristics as class-I, except for one or more limitations of wetness					
VI	Clay	Gullied lands or sand dunes	10 or less	Very rapid	>33	Marginal land

Table 2. Suitability criteria for turmeric crop¹⁴

Site characteristics		Suitability criteria			
		High	Moderate	Marginal	Not suitable
Physiography	Elevation (m)	500–1000	1000–1500	1500–2000	>2000
	Slope (%)	0–3	3–8	8–15	>15
	Aspect	Flat, southeast, south	Southwest	Northeast, east, west	North, northwest
Soil	Drainage	Well-drained	Moderately well-drained	Imperfectly drained	Poorly drained
	Land capability classes (LCC)	II	III	IV	VI
	pH	5.8–7.0	4.8–5.7 7.1–7.5	4.5–4.7 7.6–8.5	<4.5 >8.5
	P ₂ O ₅ (kg/ha)	>56	22.5–56	<22.5	–
	K ₂ O (kg/ha)	>337.5	136–337.5	<136	–
Climate	Average annual rainfall (mm)	1500–2000	1000–1500	800–1000	<800
	Mean temperature (°C)	28–32	20–27 33–37	10–19 38–40	<10 >40

criteria¹⁴. Table 2 shows the criteria for identification of suitable sites for turmeric cultivation in the Jaintia Hills district of Meghalaya. Each thematic layer had been divided into four different suitability classes, viz. highly suitable, moderately suitable, marginally suitable and unsuitable/not suitable. All input vector layers were converted to raster layers and maintained for further processing using AHP.

MCDM approach

In MCDS approach, several criteria were combined to form a single index for evaluation. Each thematic layer has a genuine importance based on the weightage that has been allocated through the GIS platform in MCDM. GIS platforms are best suited to handle a wide range of multi-spatial, temporal and multi-scale data using cost-effective approach and in a timely manner. AHP is a MCDM tool which decomposes complex problems into a hierarchy, and helps in solving problems and making logical decisions¹⁶. AHP judges thematic layers with the help of pairwise comparison matrix (Table 3). The weightages are finally aggregated.

Decision rule generation using AHP

AHP is a complex mathematical process used for solving decision-making problems. Using pairwise comparison, AHP calculates a weight for each criterion (w_i) by taking the eigenvector analogous to the largest eigenvalue of the matrix, finally normalizing the sum of the criteria to unity¹⁷.

$$\sum_{i=1}^n w_i = 1. \tag{1}$$

Rank was calculated for each criterion using Saaty’s scaling ratio⁷. An equation of $n \times n$ order can be defined as

$$A = [a_{ij}], i, j = 1, 2, 3, \dots, n, \tag{2}$$

where a_{ij} are the elements of matrix A and the matrix displays the property of reciprocity, which is described as follows

$$a_{ij} = \frac{1}{a_{ji}}, \tag{3}$$

Table 3. Pairwise comparison matrix for turmeric using analytical hierarchical process

Class	Elevation	Slope	Aspect	LCC	Soil pH	P ₂ O ₅	K ₂ O	Soil drainage	Rainfall	Temperature
LCC	7	4	6	1	3	5	5	2	9	9
Drainage	7	4	7	0.50	3	5	5	1	8	9
Soil pH	6	2	5	0.33	1	4	4	0.33	7	7
Slope	4	1	3	0.25	0.50	2	2	0.25	5	5
K ₂ O	4	0.50	3	0.50	0.25	2	1	0.20	5	5
P ₂ O ₅	3	0.50	2	0.50	0.25	1	0.50	0.20	4	4
Aspect	2	0.25	1	0.17	0.50	0.50	0.33	0.14	3	4
Elevation	1	0.33	0.50	1/7	0.17	0.33	0.25	0.14	2	3
Rainfall	0.50	0.20	0.33	0.14	0.14	0.25	0.50	0.13	1	2
Temperature	0.33	0.20	0.25	0.11	0.14	0.25	0.20	0.11	0.50	1
Column total	34.83	12.98	28.08	3.50	8.95	20.33	18.78	4.50	44.50	49.00

After generation of a_{ij} matrix, it is then normalized again as matrix B .

$$B = [b_{ij}], i, j = 1, 2, 3, \dots, n, \tag{4}$$

where B is normalized to A .

$$B = \frac{a_{ij}}{\sum_{i=1}^n a_{ij}}, i, j = 1, 2, 3, \dots, n. \tag{5}$$

Finally, each weight for each layer is calculated as

$$w_i = \frac{\sum_{j=1}^n b_{ij}}{\sum_{i=1}^n \sum_{j=1}^n b_{ij}}, i, j = (1, 2, 3, \dots, n). \tag{6}$$

For matrix B , the relationship between the largest eigenvalue (λ_{max}) and the corresponding eigenvector (W) is represented using eqs (7)–(9)

$$BW = \lambda_{max}W, \tag{7}$$

To check the consistency of the pairwise matrix we calculated the consistency index (CI) and finally consistent ratio (CR). The latter provides information about the likelihood or randomness in the result of pairwise comparison matrix.

$$CR = \frac{CI}{RI}. \tag{8}$$

Consistency index can be calculated as follows

$$CI = \lambda_{max} - \left(\frac{n}{n-1} \right). \tag{9}$$

If the calculated CR is less than 0.01, the weightages of different thematic layers are considered to be consistent. If not, there is a need of reconsideration and reconstruction of the pairwise comparison matrix^{10,18}.

Turmeric potential index generation using AHP

Overlaying using AHP, different thematic layers were multiplied to their respective priority vectors. Ranks had already been decided with the help of experts to judge the importance of each subclass inside a thematic layer.

In this study the following formulae have been used to overlay different thematic layers

$$\begin{aligned} TPI &= L \times PV + D \times PV + SP \times PV + S \times PV \\ &+ K \times PV + P \times PV + A \times PV + E \times PV + R \times PV \\ &+ (T \times PV) = L \times 0.27 + D \times 0.24 + SP \times 0.15 \\ &+ S \times 0.092 + K \times 0.077 + P \times 0.058 + A \times 0.041 \\ &+ E \times 0.031 + R \times 0.021 + (T \times 0.017), \end{aligned}$$

where TPI, E , S , A , L , SP , P , K , D , R and T represent turmeric potential index, elevation, slope, aspect, LCC, soil pH, available phosphorus, available potassium, drainage, average annual rainfall and mean temperature respectively. PV is the priority vector value for each respective theme.

Class size decision

Suitability zones were classified using generated mean (\bar{x}) and standard deviation (σ) from TPI, as follows

$$\text{Not suitable} = TPI \leq \bar{x} - \sigma.$$

$$\text{Marginally suitable} = TPI \geq \bar{x} - \sigma \text{ and } TPI \leq \bar{x}.$$

$$\text{Moderately suitable} = TPI > \bar{x} \text{ and } TPI < \bar{x} + \sigma.$$

$$\text{Highly suitable} = TPI \geq \bar{x} + \sigma.$$

Calculation of TPI using WOA

In case of WOA, to make the calculation easier we have normalized the sum of weightages as 1 (one). Ranks

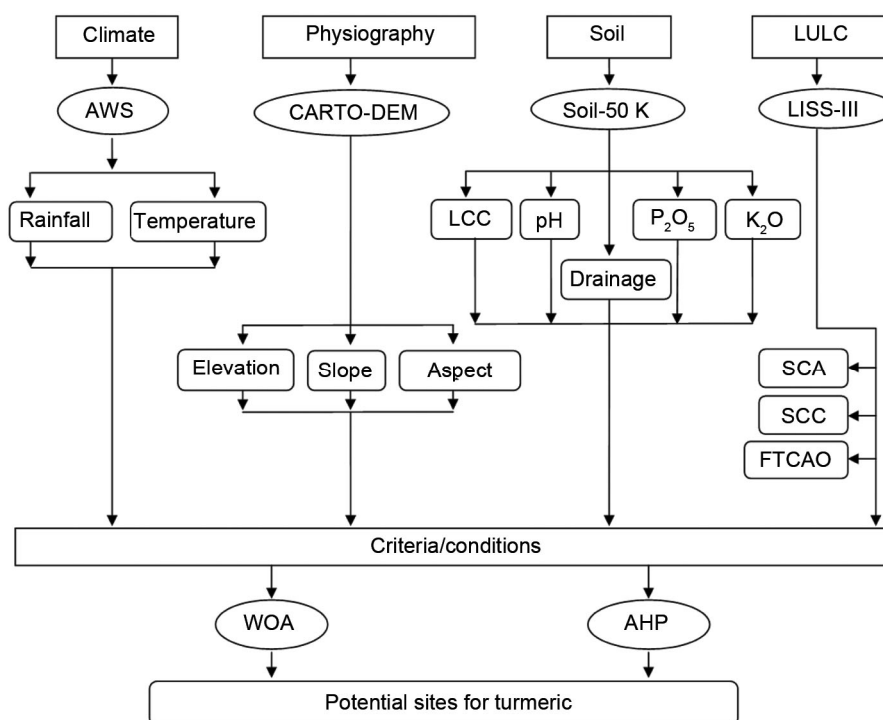


Figure 2. Overall methodology adopted for weighted overlay analysis (WOA) and analytical hierarchical process (AHP).

represent the importance of subclasses of a particular theme. The sum of the ranks of individual themes was 100 (ref. 19). The potential turmeric cultivation zones were obtained by overlaying all the thematic maps through weighted overlay methods using ArcGIS software. Figure 2 provides a stepwise description of the methodology used.

TPI was generated as the sum of the product of weightage and rank of each thematic layer, using the following formula²⁰

$$TPI = \frac{(Ewr + Swr + Awr + Lwr + SPwr + Pwr + Kwr + Dwr + Rwr + Twr)}{\text{Total weightage}}$$

where wr denotes product of weightage and rank for each layer, and E, S, A, L, SP, P, K, D, R and T represent elevation, slope, aspect, LCC, soil pH, available phosphorus, available potassium, drainage, average annual rainfall and mean temperature respectively.

Results and discussion

It was observed that FTCAO occupied the largest area (42.08% of TGA) followed by WL (25.47%), FL (24.85%), BUL (3.27%), AL (2.98%), WB (0.93%), SCC (0.34%) and SCA (0.07%) in Jaintia Hills (Figure 3 and Table 4). FTCAO, SCC and SCA were considered for

identification of suitable sites for turmeric cultivation (Figure 3 and Table 4). The producer’s accuracy, user’s accuracy, overall accuracy and KHAT were found to be 72.22–100.00%, 72.22–100%, 0.84 and 0.78 respectively (Table 5).

The entire study area was divided into three classes based on elevation, i.e. highly suitable (500–1000 m), moderately suitable (1000–1500 m) and marginally suitable (1500–2000 m) for turmeric cultivation. It was observed that 58.8% of TGA was highly suitable, 41% moderately suitable and 0.2% marginally suitable for turmeric cultivation in Jaintia Hills based on elevation (Figure 3). Again, the study area was classified into seven slope classes, i.e. 0–1%, 1–3%, 3–8%, 8–15%, 15–33%, 33–50% and >50% (Figure 3). It was observed that only 6% each of TGA was highly suitable and moderately suitable, and 13% of TGA was marginally suitable for turmeric cultivation in Jaintia Hills. However, 75% of TGA was found to be unsuitable for turmeric cultivation (Figure 3). Jaintia Hills was also classified into nine aspect classes, viz. east, flat, north, northeast, northwest, south, southeast, southwest and west (Figure 3). It was observed that 34% of TGA was highly suitable, 12% moderately suitable and 49% marginally suitable for turmeric cultivation in Jaintia Hills. Also, 5% area was found to be unsuitable for turmeric cultivation in Jaintia Hills based on aspect (Figure 3).

Soil drainage was categorized into three classes, viz. well-drained area, moderately well-drained area and

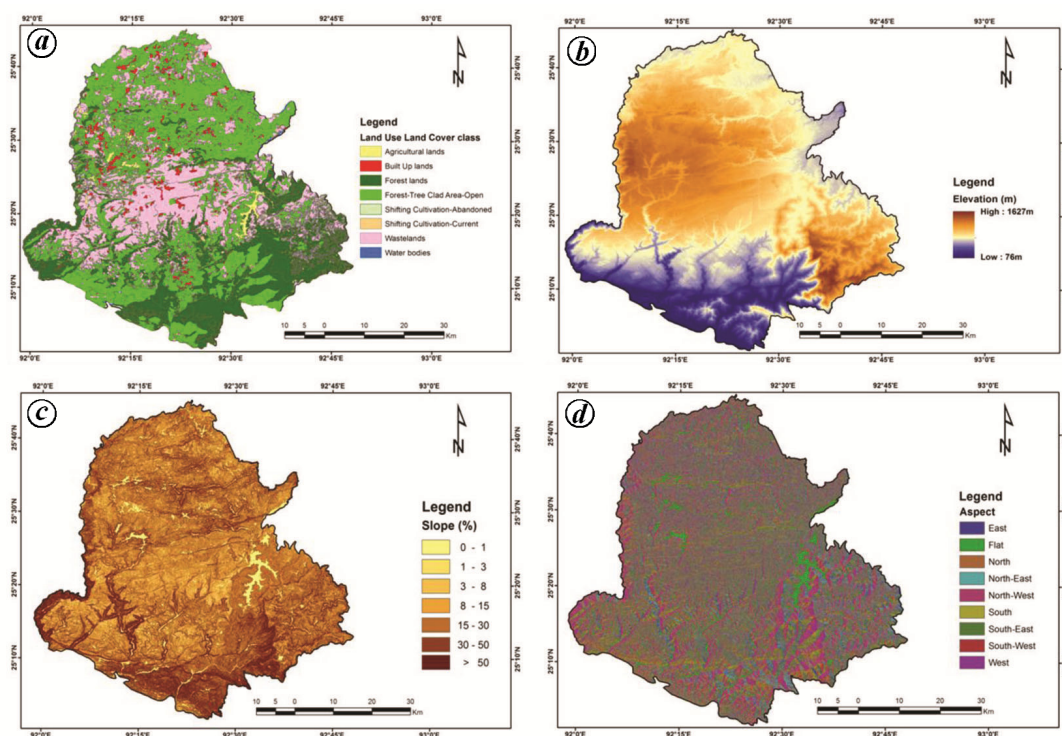


Figure 3. (a) Land-use land-cover (LULC), (b) elevation, (c) slope and (d) aspect of Jaintia Hills.

Table 4. Area under different land-use land-cover (LULC) classes in Jaintia Hills, Meghalaya, India

LULC class	Area (ha)	Total geographical area (%)
Agriculture land	11,379.52	2.98
Built-up land	12,507.05	3.27
Forest land	94,916.39	24.85
Tree-clad area open	160,713.30	42.08
Shifting–abandoned	248.35	0.07
Shifting–current	1,302.07	0.34
Wastelands	97,279.85	25.47
Water bodies	3,553.49	0.93
Total	381,900.00	100.00

poorly drained area (Figure 4). However, habitation and water bodies were not classified. It was observed that 52% area was moderately suitable, 42% highly suitable and 2% marginally suitable for turmeric cultivation in Jaintia Hills based on soil drainage (Figure 4). Again, four LCCs were found in Jaintia Hills, namely II, III, IV and VI. However, areas under habitation and water bodies were excluded from the classification since we were only dealing with shifting cultivation areas and tree-clad areas. Only 9% area under LCC II was highly suitable for turmeric cultivation (Figure 4).

Soils of Jaintia Hills were classified into extremely acidic, very strongly acidic, strongly acidic, moderately acidic, slightly acidic and neutral based on soil pH

(Figure 4). It was observed that 38% of TGA was highly suitable, 43% areas were moderately suitable and 12% marginally suitable for turmeric cultivation in Jaintia Hills based on soil acidity. Rest of the areas, including habitation and water bodies were considered as unsuitable for turmeric cultivation (Figure 4). Again, available P_2O_5 was found to be medium (22.5–56 kg/ha) to high (56 kg/ha) (Figure 4). It was observed that 69% of TGA was highly suitable and 27% moderately suitable for turmeric cultivation in Jaintia Hills based on available P_2O_5 (Figure 4). Similarly, available K_2O was categorized into three classes, viz. low (<136 kg/ha), medium (136–337.5 kg/ha) and high (>337.5 kg/ha) (Figure 4). It was observed that 54% of TGA was moderately suitable, 35% was highly suitable and 7% was marginally suitable for turmeric cultivation in Jaintia Hills based on available K_2O content (Figure 4).

Average annual rainfall of Jaintia Hills was found to vary from 1533 to 4355 mm. High rainfall occurred in the southern and central parts of Jaintia Hills and low rainfall was recorded in the northwestern part. The entire region was found to be highly suitable for turmeric cultivation based on average annual rainfall (Figure 5). The mean temperature in Jaintia Hills varied from 17°C to 23°C. The southeastern part was found to be warmer compared to the other areas. The lowest temperature was observed around the western parts of Jaintia Hills (Figure 5). It was observed that 54% of TGA was highly suitable and 46% was moderately suitable for turmeric

Table 5. Accuracy assessment of LULC of Jaintia Hills¹²

LULC	Referenced data					Row total	User's accuracy
	AL	BUL	FL/FTCAO	SCC/SCA	WL		
Classified data							
AL	13				1	14	92.86
BUL	2	13	2		1	18	72.22
FL/FTCAO			12			12	100.00
SCC/SCA				1		1	100.00
WL	3	2	1		24	30	80.00
Column total	18	15	15	1	26	75	
Producer accuracy	72.22	86.67	80.00	100.00	92.31		
Overall accuracy				0.84			
KHAT				0.78			

LULC, Land-use land-cover; AL, Agricultural land; BUL, Built-up land; FL, Forest land; FTCAO, Forest-tree clad area–open; SCC, Shifting cultivation–current; SCA, Shifting cultivation–abandoned; WL, Wastelands.

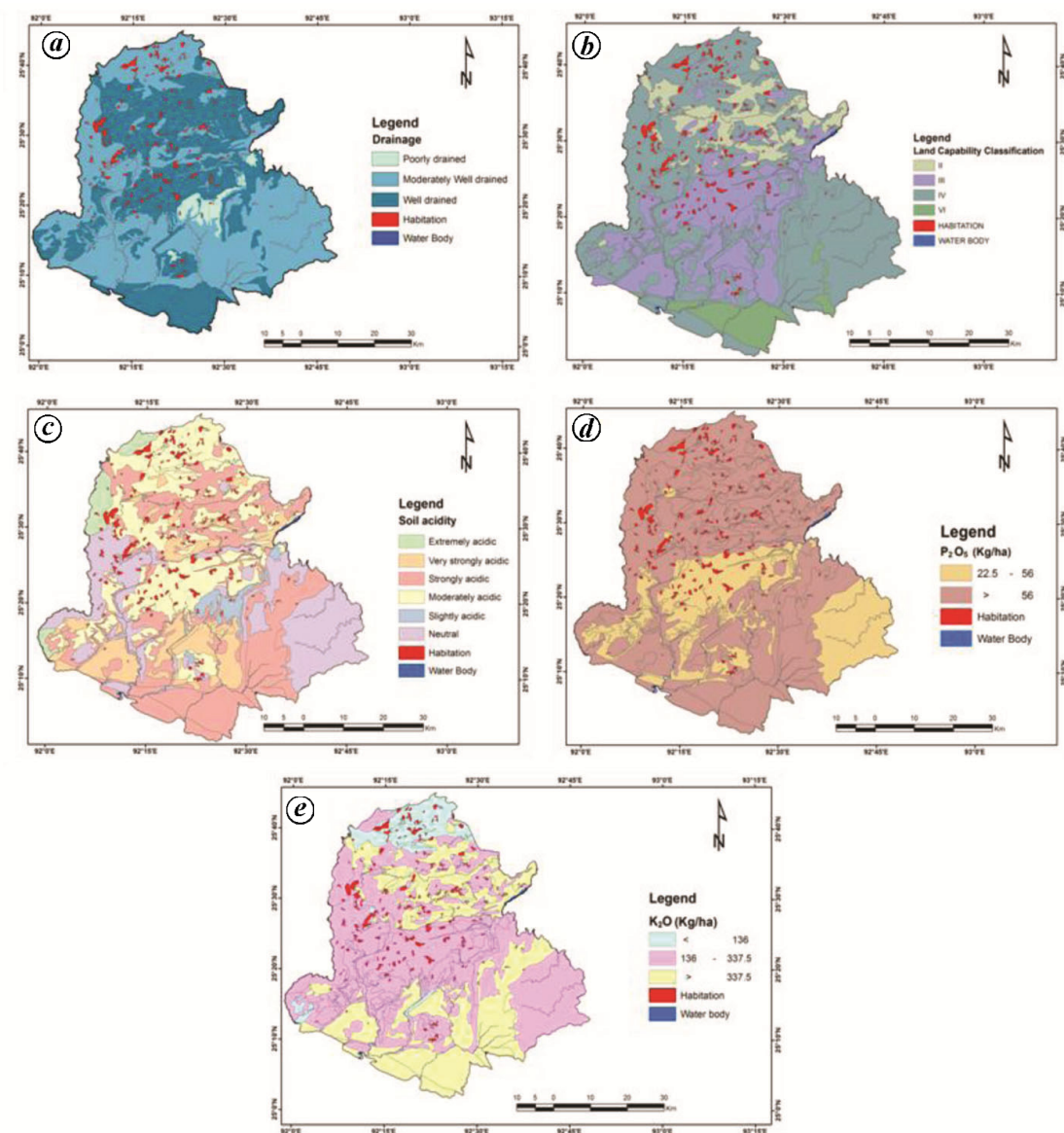


Figure 4. (a) Soil drainage, (b) land capability classes (LCC), (c) soil acidity, (d) available P₂O₅ and (e) available K₂O of Jaintia Hills.

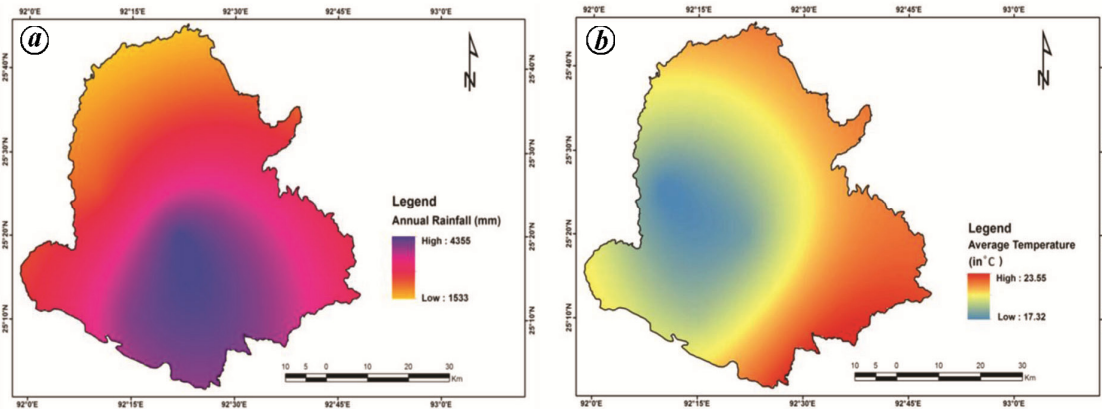


Figure 5. Spatial distribution of (a) mean annual rainfall and (b) mean temperature in Jaintia Hills.

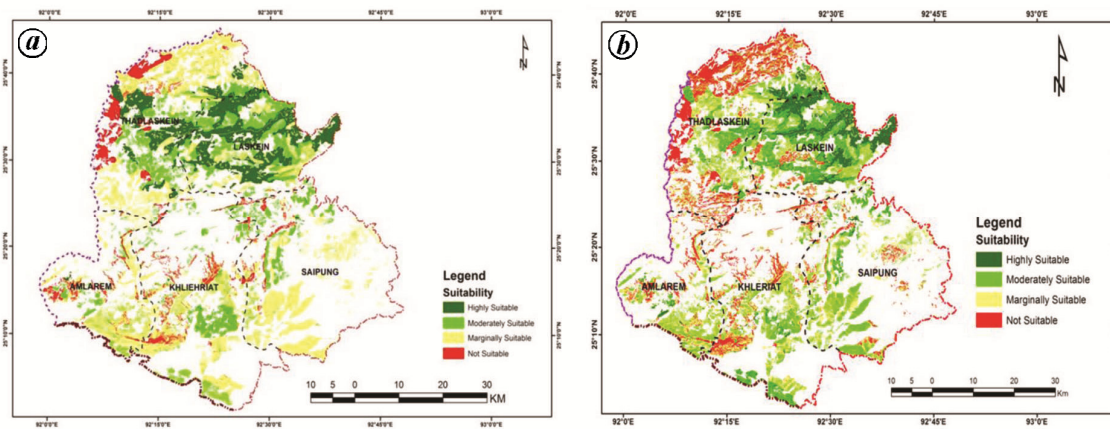


Figure 6. Suitable sites of turmeric cultivation generated using (a) AHP and (b) WOA in Jaintia Hills.

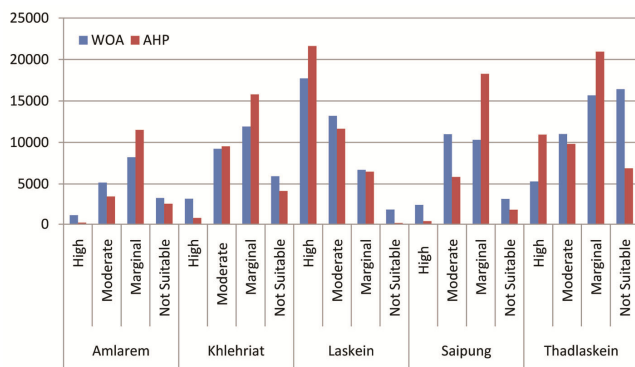


Figure 7. Suitable areas for turmeric cultivation in Community and Rural Development blocks of Janitia Hills.

cultivation. The whole area was found to be suitable for turmeric cultivation based on temperature in Jaintia Hills (Figure 5).

Site suitability analysis for turmeric cultivation using AHP

AHP yielded a different result compared to WOA for site suitability analysis. There was a sharp decrease (by 10%)

in the unsuitable area. Again, marginally suitable areas occupied a sum of 72,967.48 ha (45% of TGA). Similarly, moderately suitable and highly suitable areas occupied 25% and 21% of TGA respectively. Laskein Community and Rural Development (C&RD) block represented highest area under highly suitable class (21,624.35 ha, 64% of TGA), while lowest area under highly suitable class was found in Amlarem C&RD block (192.57 ha, <1% of TGA). Thadlaskein and Khlehriat represented highest unsuitable areas for turmeric cultivation (45% and 26% of TGA respectively). Figures 6 and 7 show suitable areas for turmeric cultivation in Jaintia Hills generated using AHP and WOA.

Site suitability analysis for turmeric cultivation using WOA

Potential sites for turmeric cultivation were categorized into four classes, viz. highly suitable, moderately suitable, marginally suitable and not suitable. The study revealed that 29,534.47 ha was highly suitable (18%), 49,590.75 ha was moderately suitable (31%) and 52,785.47 ha was marginally suitable (32%) for turmeric

cultivation in Jaintia Hills. However, 30,353.02 ha was found to be unsuitable (19%) for turmeric cultivation. Jaintia Hills consists of five C&RD blocks, viz. Amlarem, Khlehriat, Laskein, Saipung and Thadlaskein. The largest areas under highly suitable category for turmeric cultivation were found in Laskein (10.92%) followed by Thadlaskein (3.26%), Khleriet (1.90%), Saipung (1.44%) and Amlarem (0.67%). Similarly, the proportion of moderately suitable area found in Laskein was (8.14%) followed by Thadlaskein (6.78%), Saipung (6.77%), Khlehriat (5.70%) and Amlarem (3.17%). On the other hand, 9.66% area in Thadlaskein, 7.34% in Khleriet, 6.34% in Saipung, 5.06% in Amlarem and 4.12% area in Laskein were found to be marginally suitable for turmeric cultivation (Figures 6 and 7).

Conclusion

The present study reveals that a large extent of areas is underutilized in Jaintia Hills which can be brought under cultivation. Even when we consider the highly suitable areas, which is nearly 40,000 ha, there is huge potential for the region to increase area under turmeric crop. Quick satellite data acquisition, management, processing and understanding seasonal variability are some of the added advantages. This study has demonstrated the strength of remote sensing and geographic information system in the identification of potential sites for turmeric cultivation in Jaintia Hills of Meghalaya; however, the problem lies in determining in validation and extent of veracity for both the methods.

In general, AHP is considered to be superior to WOA since it gives a valid confirmation of weightage using CR. Although WOA and AHP are based on overlaying different thematic layers according to weightage and rank among the numerous parameters within the layer, weighted analysis solely depends on experts' knowledge for the determination of weight and rank, which can vary according to the one's judgement.

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ACKNOWLEDGEMENTS. This work was undertaken as part of a National Programme entitled 'Coordinated Horticulture Assessment and Management using Geoinformatics' (CHAMAN) with financial assistance from Mahanalobis National Crop Forecast Centre, Department of Agriculture, Cooperation and Farmers' Welfare, Ministry of Agriculture and Farmers' Welfare, Government of India.

Received 20 March 2019; revised accepted 22 January 2020

doi: 10.18520/cs/v118/i8/1246-1254