




Promoting Agricultural Sustainability in Semi-arid Regions: An Integrated GIS–AHP Assessment of Land Suitability for Encouraging Crop Diversification

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Abstract

Informed decision regarding cultivating the right crop in the right land will guarantee maximum production, which is the need of the hour to meet the world's burgeoning food demand and to ensure the sustainability of agriculture. The present study aimed to identify the land suitability for major crops in the semi-arid ecosystem of Palani block in Tamil Nadu by integrating the analytical hierarchy process (AHP) and geographic information system (GIS). Soil slope and various soil characteristics influencing crop growth such as soil depth, texture, drainage, gravelliness, pH and organic carbon were considered for assessing the land suitability. Weights and scores were assigned to the selected criteria and their respective sub-criteria based on their relative significance in influencing crop growth. It was found that soil drainage and texture were the most influencing factors for paddy cultivation, with weights of 0.49 and 0.27, respectively. For field beans, coconut, and guava, texture and depth were identified as the major influencing factors with high weightages ranging from 0.26 to 0.40. Results indicate that about 22% (8627 ha) of the study area was highly suitable for field beans, followed by paddy (18%). In contrast, paddy and coconut registered the largest land area under the marginally suitable class and were deemed unsuitable for about 19% and 21% of the land, respectively. For guava and field beans, respectively 37% and 44% of the land were found moderately suitable while 77% and 76.6% of the land were found suitable. Soil texture, soil depth, and drainage were identified as the major impediments to coconut and paddy suitability. An error matrix was generated by comparing the land suitability derived through the AHP–GIS method with the farmers' opinions on land suitability for different crops. It indicated a high agreement between the suitability classes and farmers' opinion for field beans, followed by coconut, guava and rice with kappa indices of 0.64, 0.51, 0.49 and 0.40 and overall accuracy of 75%, 65%, 62% and 60%, respectively. The present study not only helps in identifying suitable areas for crop cultivation, but also recommends land management strategies to each land parcel to improve land productivity and sustainability.

Keywords Land suitability assessment · Geographic information system · Analytical hierarchy process · Weighted overlay · Error matrix

Introduction

Soils represent one of the world's most intricate and diverse ecosystems, serving as the foundational bedrock of human sustenance by providing 98.8% of the food supply, alongside

a plethora of invaluable ecosystem services (FAO, 2018). However, the world's soils are currently facing unprecedented pressures, driven by the escalating demand for food production, fiber, energy, and infrastructure development. This demand is intensifying at an alarming rate due to the accelerating growth of the global human population, which is projected to reach 9.8 billion by the year 2050 (UN, 2017). Consequently, to attain global food security, food production must undergo a staggering 70% increase between 2005 and 2050 (ELD, 2015). This surge in food and fiber production, necessary for global food security, has to be made by increasing productivity rather than expansion of arable land,

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posing an unprecedented challenge amidst the backdrop of ongoing climate change, urbanization, and population growth (Kopitkce et al., 2019). In this context, effective land management emerges as a critical linchpin for ensuring food security, exerting a profound influence on agricultural productivity and the sustainable utilization of our land resources (Critchley et al., 2023). Agricultural production and productivity rely on various factors like soil, climate, management practices, etc., which are highly variable with space and time, wherein, the remote sensing helps in myriad ways to identify the land use and its extend, monitoring of agricultural crop, soil health and water management, yield prediction, etc. The increased availability of open-source data with high resolution increases the applicability of remotely sensed data. Informed land management practices, underpinned by rigorous land suitability assessments, occupy a pivotal role in navigating this complex landscape (Ozsahin et al., 2022). Land suitability analysis ascertains the land suitability to the specific land use for their aptness by considering its potentials and constraints, which is the prerequisite for land use planning (Ramamurthy et al., 2020) which can cast light upon the regions susceptible for various environmental challenges. Typically, soil factors (e.g., depth, texture, fertility), climatic parameters (e.g., rainfall, temperature), and physiographic variables (e.g., slope, elevation) are considered in the quantitative assessment of land suitability. Employing multiple criteria offers decision-makers several options and this helps in identifying land uses having long-term sustainability such as AHP, Fuzzy logic and principal component analysis. In recent years, the AHP stands out as one of the widely adopted, simple and reliable multi-criteria decision-making processes which segregate multi-criteria problems into several hierarchy levels, encompassing objectives, criteria and alternatives, thereby reducing bias (Saaty, 1990). It evaluates criteria through pairwise comparison and assigns weights to each parameter by using a pairwise comparison matrix based on its significance in determining crop suitability (Zhang et al., 2015). To further enhance decision-making in land suitability assessment, geographic information system (GIS) has become an indispensable tool. By integrating AHP with GIS, accurate and efficient land suitability maps can be generated with suitable alternatives (Mendas & Delali, 2012). Even though numerous studies attempted on multicriteria based decision making on land suitability at the national and international levels, there have only been a few for Tamil Nadu (Sathiyamurthi et al., 2022) and no studies were documented for the Palani block of the Dindigul district, where vegetable crop cultivation is prioritized despite the land's suitability assessment. Hence, assessing the land suitability for the major crops is imperative for enhanced crop production eventually for agricultural sustainability. The present study was conducted to make a comprehensive land suitability assessment for the

Palani block, focusing specifically on major crops such as paddy, field bean, coconut, and guava. To accomplish this, we employed an integrated approach combining the AHP with GIS techniques, tailored to the unique agricultural landscape of the Tamil Nadu uplands.

Material and Methods

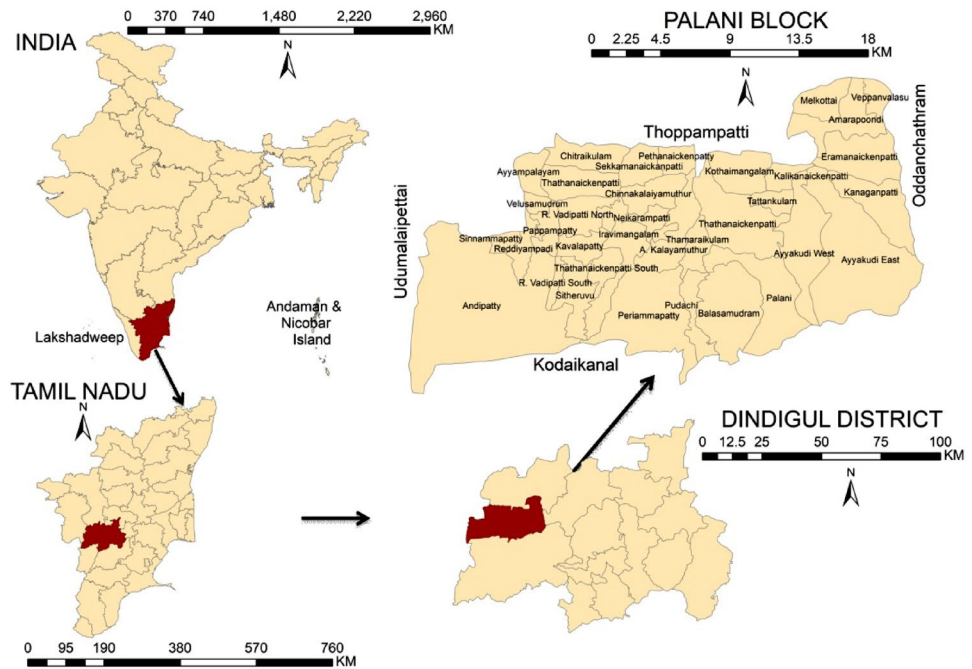
Study Area

The study was conducted in the Palani block of Dindigul district, Tamil Nadu which lies between $77^{\circ} 18' 50''$ and $77^{\circ} 37' 17''$ E longitude and $10^{\circ} 21' 18''$ and $10^{\circ} 32' 27''$ N latitude covering a total geographical area of 39,960 ha which is situated in the north-leeward down direction of Palani hill ranges, which form the northern spur of the Western Ghats, this region falls under Tamil Nadu uplands (Agroecological Subregion (AESR) 8.1) (Fig. 1). Elevation in the upland areas ranges from 280 to 400 m above mean sea level (MSL) while hill ranges extend up to 1400 m MSL. Average annual rainfall is 760 mm and the area is classified under semi-arid uplands. The length of the growing period (LGP) ranges from 90 to 120 days.

Several seasonal streams e.g., Kuthiraiyar, Varatham-anathi, Palar and Porunthalar, originating from the Palani hill ranges (a part of the Western Ghats) drain through the Palani block. Physiographically, the area is divided into four landforms based on slope and relief features viz. foothills, upper pediplain, lower pediplain, and valley barring hill ranges and isolated hillocks. The major crops cultivated in this region are rice (*Oryza sativa*), maize (*Zea Mays*), sorghum (*Sorghum bicolor*), cotton (*Gossypium* sp.), groundnut (*Arachis hypogea*), beans, vegetables (tomato, onion, drumstick, cabbage, radish, etc.), coconut (*Cocos nucifera*) and horticultural fruit crops like guava (*Psidium guajava*) and mango (*Mangifera indica*).

Criteria Used for AHP–GIS Integrated Land Suitability Analysis

The important soil properties which were considered as the criteria for assessing the land suitability in the present study were selected based on FAO (1976) and the land suitability criteria established by Naidu et al. (2006). In addition to pedological criteria, the slope was also taken into consideration as a topographic criterion. However, while climatic factors such as rainfall and temperature impact soil properties, plant growth and yield (Chen, 2016), they were not considered as criteria for the present suitability analysis due to the negligible variability in rainfall distribution and temperature in the study area except Palani hill ranges (i.e., Reserve Forest).

Fig. 1 Location map of the study area

Slope

The slope map for the study area was generated using the ALOS PALSAR DEM (digital elevation model) at 12.5 m spatial resolution in ArcGIS 10.7.1. The DEM data was downloaded from the Alaska Satellite Facility website (<https://search.asf.alaska.edu/>).

Pedological Factors

Sentinel-2 satellite imagery was delineated into different polygons for selecting profiles based on the image characteristics and digital elevation model at 1:10,000 scale and overlaid with road, drainage networks and permanent features as a base map. Preliminary traversing was done with the help of base maps and the deviations from the base maps on groundtruthing were marked on the map. A total of 172 profiles were dug in the study area and their site characteristics and morphological characteristics of the pedon (soil depth, surface gravels, drainage) were examined in the field following the standard procedures outlined in the Soil Survey Manual (Soil Survey Staff, 2014). Soil drainage was assessed based on frequency and duration of wet periods, occurrence of mottles and gleying as site characteristics. Studied profiles were grouped into 16 soil series using the series identifying characteristics and mapped as 16 soil

series and 49 mapping units in the study area encompassing foothills, upper pediplain, lower pediplain and valley. Horizon-wise soil samples (total of 72) were collected from typifying pedons of each series (16 series) and analyzed for different physical (texture) and chemical (pH, organic carbon) properties in the laboratory. Soil texture was determined following the International Pipette method (Richards, 1954), and organic carbon content was estimated by the Walkley and Black (1934) method. Soil pH values were measured in 1:2.5 soil: water suspension using the potentiometric method (Jackson, 1973). This dataset was used to derive pedological criteria for land suitability analysis.

Land Suitability Assessment

The methodology employed for land suitability assessment by integrating AHP and GIS approach is outlined in Fig. 2.

Analytical Hierarchy Process (AHP)

In the AHP method, a pairwise comparison matrix was created to compare each factors with one another and were given with rating according to their relative preferences as per Saaty's rating scale (Table 1), which ranges from 1 to 9. While comparing two factors, for instance, the factor A is five times more significant than factor B signifies that factor

B is 1/5 times important as factor A. Similar manner all the criteria (factors) were with each other. These weights are normalized using a pairwise comparison matrix, resulting in values ranging from 0 to 1, with their sum totalling 1. Consideration of the relative importance of criteria and pairwise comparison for land suitability was based on experts' opinions. During the pairwise comparisons, the consistency ratios (CR) were computed to validate the consistency of the judgments made in pairwise comparisons. A CR value below 0.1 indicates acceptable consistency in the pairwise comparison matrix, allowing the assessment to proceed. If the CR exceeds 0.1, the judgements for the rating in pairwise

comparison were reassessed to minimize the inconsistency (Kahsay et al., 2018).

$$Consistencyratio(CR) = \frac{CI}{RI}$$

where CI is the consistency index and RI is the random inconsistency index (Saaty et al., 2012). The random inconsistency index provided by Saaty (2012) is given in Table 2.

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

Fig. 2 Methodology flow chart

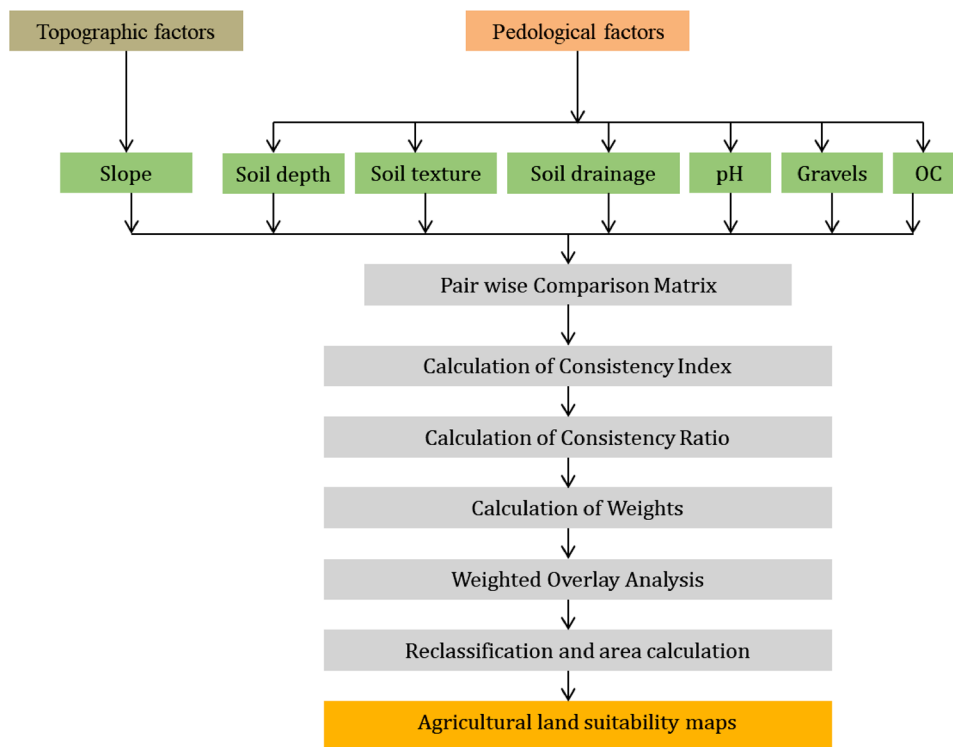


Table 1 Saaty’s pairwise comparison scale

Importance rating	Definition	Explanation
9	Extremely important	Judgement extremely favors one over another
7	Very much more important	Judgement very strongly favors one over another
5	Much more important	Judgement strongly favors one over another
3	Somewhat more important	Judgement slightly favors one over another
1	Equally important	Two factors contribute equally
2, 4, 6, 8	Intermediate values	When compromise needed

Table 2 Random inconsistency index (RI) (Saaty, 2012)

Number of criteria (N)	1	2	3	4	5	6	7	8	9	10	11	12
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.46	1.49	1.51	1.48

where λ_{max} is the largest eigenvalue of the matrix, and n is the number of criteria used for comparison. Sub-criteria level scores were assigned on the parameters that affected the suitability positively, while the parameters that negatively affected the crop suitability were assigned with low scores (Table 4).

Weighted Overlay Analysis

A decision matrix is generated by comparing the criteria in pairwise comparisons, and ensuring consistency in this process helps in continued decision-making. Subsequently, the reclassified thematic raster layers were further used in a weighted overlay analysis in a GIS environment. The thematic vector layers of all criteria were converted to raster format with equal cell size using conversion and resampling methods in Arc-GIS 10.7.1. The re-sampled raster layers were subsequently reclassified into sub-criteria to execute weighted overlay analysis. This analysis was used to integrate the thematic layers and to generate land suitability

maps based on the weights calculated in ArcGIS 10.7.1. Additionally, sub-criteria were scored following the guidelines from FAO (1976) (Table 3 and 4). Land suitability maps were prepared based on the Suitability Index (SI) through weighted overlay analysis, which was calculated using the formula,

$$SI = \sum_{i=1}^n W_i R_i$$

where W_i is the weightage of each criterion and R_i is the score of each sub-criterion.

All the criteria raster maps were imported into ArcGIS 10.7.1 environment, with criteria weightages inputted as percent influence with the condition that the total weight does not exceed 100%. Sub-criteria scores were overlaid using weighted overlay analysis. The resulting land suitability maps were categorized into four classes as highly suitable, moderately suitable, marginally suitable and non-suitable (FAO, 1976). The permanent features e.g., reserve

Table 3 Pairwise comparison and weights of criteria for selected crops

Criteria	Slope	Soil depth	Texture	Drainage	pH	Gravels	OC	Weights	CI	RI	CR
<i>Paddy</i>											
Slope	1	7	1/5	1/5	5	–	–	0.150	0.043	1.12	0.03
Depth	1/7	1	1/7	1/9	3	–	–	0.050			
Texture	5	7	1	1/5	9	–	–	0.272			
Drainage	5	9	5	1	7	–	–	0.493			
pH	1/5	1/3	1/9	1/7	1	–	–	0.035			
<i>Field bean</i>											
Slope	1	1/4	1/3	1/2	4	3	–	0.120	0.099	1.27	0.08
Depth	4	1	1/2	3	5	3	–	0.256			
Texture	3	2	1	5	7	5	–	0.384			
Drainage	2	1/3	1/5	1	3	2	–	0.119			
pH	1/4	1/5	1/7	1/3	1	1/5	–	0.037			
Gravels	1/3	1/3	1/5	1/2	5	1	–	0.086			
<i>Coconut</i>											
Slope	1	1/5	1/7	1/7	1/5	3	1/3	0.044	0.123	1.39	0.09
Depth	5	1	2	3	5	5	5	0.318			
Texture	7	1/2	1	3	5	7	5	0.276			
Drainage	7	1/3	1/3	1	3	5	5	0.178			
pH	5	1/5	1/5	1/3	1	3	1	0.082			
Gravels	1/3	1/5	1/7	1/5	1/3	1	1/3	0.032			
OC	3	1/5	1/5	1/5	1	3	1	0.070			
<i>Guava</i>											
Slope	1	1/7	1/6	1/2	3	3	1	0.067	0.127	1.32	0.09
Depth	7	1	1/5	5	9	8	7	0.295			
Texture	6	5	1	3	9	8	7	0.400			
Drainage	2	1/3	1/3	1	3	3	3	0.110			
pH	1/3	1/9	1/9	1/3	1	1/3	1/3	0.026			
Gravels	1/3	1/8	1/8	1/3	3	1	1/3	0.040			
OC	1	1/7	1/7	1/3	3	3	1	0.062			

Table 4 Scores of sub-criteria used for different crops

Criteria	Sub-criteria	Paddy	Field bean	Coconut	Guava
Slope	Nearly level (0–1%)	9	7	7	7
	Very gently sloping (1–3%)	7	7	7	7
	Gently sloping (3–5%)	5	6	5	5
	Moderately sloping (5–10%)	1	5	3	3
Depth	Very deep (> 150 cm)	7	7	7	7
	Deep (100–150 cm)	7	7	5	5
	Moderately deep (75–100 cm)	6	6	3	3
	Moderately shallow (50–75 cm)	5	5	2	3
	Shallow (25–50 cm)	2	3	1	1
Soil drainage	Very shallow (< 25 cm)	1	1	1	1
	Well	4	7	7	5
	Moderately Well	6	5	5	5
Texture	Somewhat poor	7	5	3	3
	Clay	9	5	4	7
	Clay loam	7	7	6	7
	Loam	3	7	7	7
	Loamy sand	1	5	4	6
	Sandy clay	6	7	6	6
	Sandy clay loam	4	7	7	7
	Sandy loam	3	7	5	6
Surface gravels	< 15%	–	7	7	5
	15–35%	–	5	5	3
	35–50%	–	3	3	1
pH	Neutral (6.5–7.5)	6	7	6	7
	Slightly alkaline (7.5–8.5)	6	7	4	4
	Mod. Alkaline (8.5–9.0)	5	5	4	2
	Strongly alkaline (> 9)	3	3	3	1
	Slightly acid (6–6.5)	6	7	7	5
	Strongly acid (5–5.5)	6	3	5	3
Organic carbon	Low (< 0.5%)	4	3	4	3
	Medium (0.5–0.75%)	6	5	5	4
	High (> 0.75%)	7	7	6	5

forest, settlements, mining areas, and water bodies were masked from the land use land cover map to obtain the final land suitability map of Palani block.

Validation of the AHP–GIS Method

In line with previous research highlighting the importance of integrating local farmers' knowledge with scientific methodologies (WinklerPrins, 1999), our study aimed to validate the performance of the AHP–GIS method in establishing suitability classes. To achieve this, farmers' opinion on crop suitability was acquired in the same study

area through a survey. The survey questionnaire had several questions on soil type, depth, soil erosion, agricultural technologies used, soil and land requirements for important crops, and factors considered for decision-making. The survey was conducted on 20 farmers at their farms. They were asked to rank the soil properties important to different crops as very important, important and not important. Likewise, they were asked to assess the suitability of their lands for paddy, field bean, coconut and guava as very good, good, moderate and poor. Subsequently, these suitability assessments were compared with our classification data through tabulation of the error matrix, allowing

for the estimation of overall accuracy and the kappa index. The percentage of suitability classes correctly classified is estimated as Overall accuracy (OA).

$$OA = \sum_{i=1}^n \frac{\text{Number of classes correctly classified}}{\text{Total number of classes}}$$

where n is the number of columns or rows of the error matrix. The Kappa index measures the agreement between two different classification methods. Kappa indices > 0.80 , $0.4–0.8$ and < 0.4 indicate strong, moderate and poor agreements of classification, respectively (Congalton & Green, 1998).

Results and Discussion

Soil depth, slope, texture, gravel content, drainage, pH, and OC were taken into account to determine the suitability for cultivating paddy, field beans, coconuts and guava as they are imperative in deciding plant root growth, water and nutrient holding capacity, soil erosion susceptibility and soil quality (Holmes et al., 2021; Salunkhe et al., 2023). Similar parameters were considered for soil suitability assessment in several previous studies (Roy et al., 2022). List of criteria, sub-criteria considered and their spatial distribution are represented in Table 4 and Fig. 3a–g.

Multicriteria Comparison

The pairwise comparison matrix of criteria for each crop and their weights are presented in Table 3. For land suitability of paddy, slope, soil depth, texture, drainage and pH were considered. Out of these five criteria, drainage scored the highest weightage (0.493), probably due to the significance of water storage for paddy cultivation. Soil texture was recorded as the second highest weightage (0.272). Soil drainage and texture were critical considerations for paddy because paddy grows on stagnant water and heavy soils with higher water holding capacity are desirable for its growth (Naidu et al., 2006; Shaloo et al., 2022). The slope scored comparatively lesser weightage (0.15). The weightage of different soil properties for soil suitability of paddy followed the order: drainage $>$ texture $>$ slope. The CR of the pairwise comparison matrix was 0.03 (< 0.1),

suggesting the assigned scores and calculated weightages for criteria and sub-criteria are acceptable (Ramamurthy et al., 2020).

In addition to the criteria selected for paddy, gravel contents were also added as a criterion for assessing the suitability of field beans for the Palani block as recommended by Naidu et al. (2006). Soil texture scored the highest weightage (0.384) in field beans, followed by soil depth (0.256) and drainage (0.119). The higher emphasis on soil texture might be due to its influence on soil aeration, water-holding capacity and fertility (Chen et al., 2020).

For the suitability assessment of coconut and guava, a common set of criteria was considered. Along with the criteria selected for field beans (slope, depth, texture, drainage, pH, gravel), organic carbon was also considered (Naidu et al., 2006). For coconut, soil depth was given higher weightage followed by texture, on the contrary, for guava, texture was given the highest weightage followed by depth. Drainage was found to be the third important criterion for both crops with the weights of 0.178 for coconut and 0.11 for guava (Table 3). Judgement on the ranking of the criteria for both crops registered a CR value of 0.09, signifying the inconsistency of the pairwise matrix is within the limit. Due to their importance in crop growth, soil texture and depth were consistently given significant weightages (Zolekar & Bhagat, 2015). For coconut, soil depth was a crucial factor since it influences root development and provides anchorage to the plant. Nevertheless, the nutrient supply depends on soil pH and OC which were considered as significant criteria (Roy & Saha, 2018).

Weighted Overlay Analysis (GIS)

By integrating the weights and scores of each criterion at each pixel, the final land suitability map was generated in ArcGIS using weighted overlay analysis, which is depicted in Eq. 1–4 as follows,

$$\text{Paddy} = \sum (0.15 \times \text{slope}) + (0.05 \times \text{soil depth}) + (0.272 \times \text{texture}) + (0.493 \times \text{soil drainage}) + (0.035 \times \text{pH}) \quad (1)$$

$$\text{Field bean} = \sum (0.12 \times \text{slope}) + (0.256 \times \text{soil depth}) + (0.384 \times \text{texture}) + (0.119 \times \text{soil drainage}) + (0.037 \times \text{pH}) + (0.086 \times \text{gravels}) \quad (2)$$

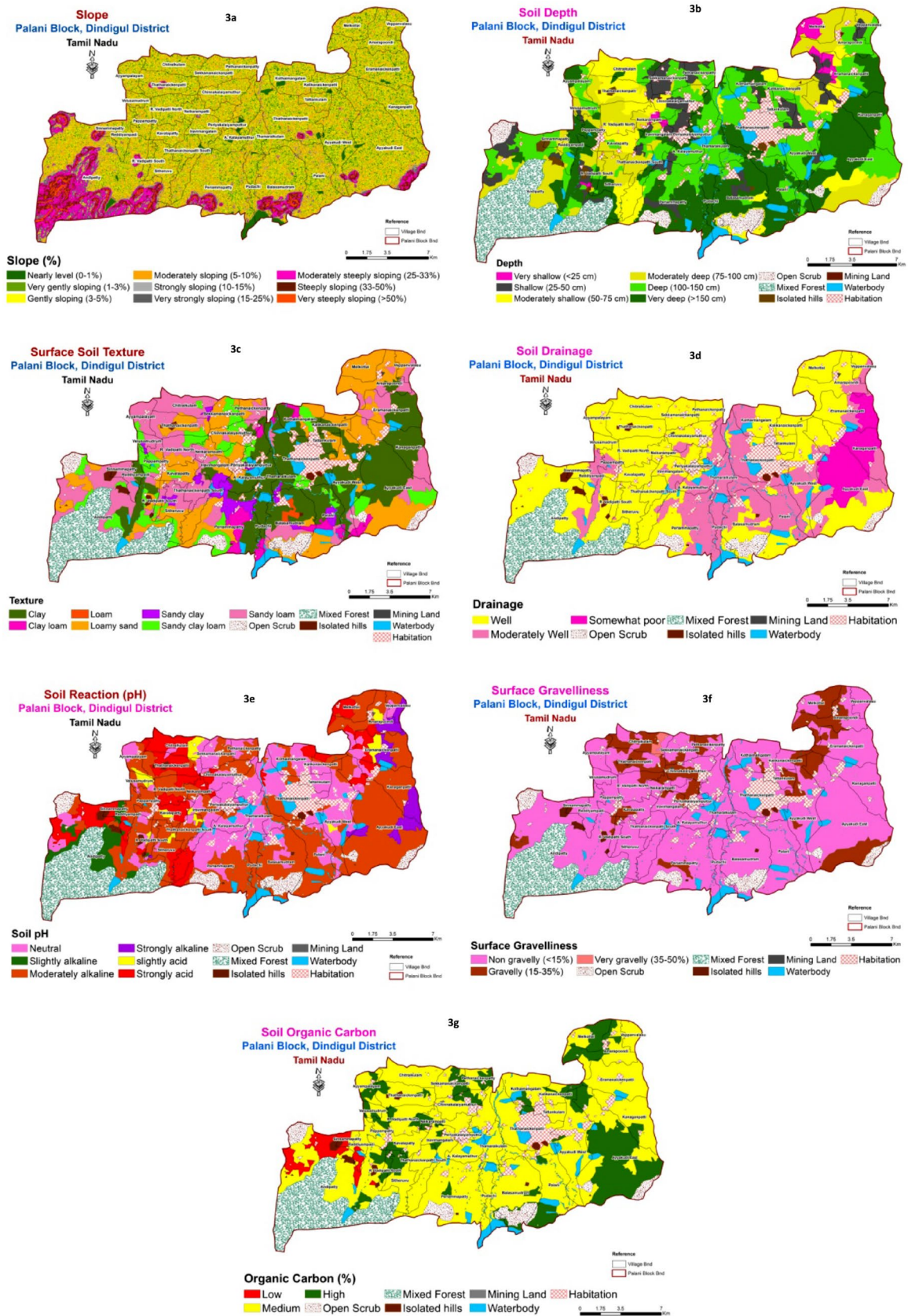


Fig. 3 a–g Thematic maps depicting slope (a) and soil properties depth (b), surface texture (c), drainage (d), pH (e), surface gravelliness (f) and organic carbon content (%) (g)

$$\begin{aligned} \text{Coconut} = & \sum (0.044 \times \text{slope}) + (0.318 \times \text{soil depth}) + (0.276 \times \text{texture}) \\ & + (0.178 \times \text{soil drainage}) + (0.825 \times \text{pH}) \\ & + (0.032 \times \text{gravels}) + (0.07 \times \text{OC}) \end{aligned} \tag{3}$$

$$\begin{aligned} \text{Guava} = & \sum (0.067 \times \text{slope}) + (0.295 \times \text{soil depth}) + (0.4 \times \text{texture}) \\ & + (0.11 \times \text{soil drainage}) + (0.026 \times \text{pH}) \\ & + (0.04 \times \text{gravels}) + (0.062 \times \text{OC}) \end{aligned} \tag{4}$$

The permanent features (including settlements, hill ranges, water bodies, open scrub, mining area, etc.) in the

final land suitability maps for paddy, field bean, and coconut are masked from the final map (Figs. 4, 5, 6, 7).

Land Suitability Assessment

By integrating AHP and GIS, the land suitability analysis was carried out to find the extent and degree of land suitability for paddy, field bean, coconut and guava by comparing crops’ specific necessities with the inherent soil properties and land features. The consistency ratio (CR) recorded 0.03, 0.08, 0.09 and 0.09 for paddy, field beans, coconut and guava, respectively (Table 3) which suggests that the weights assigned for each criterion based

Fig. 4 Suitability map for Paddy

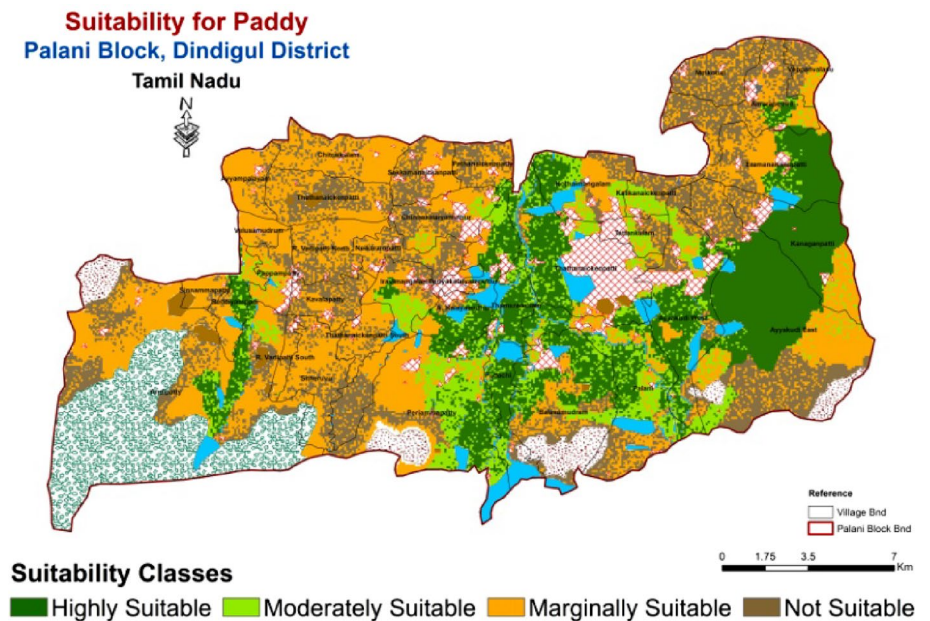


Fig. 5 Suitability map for Field bean

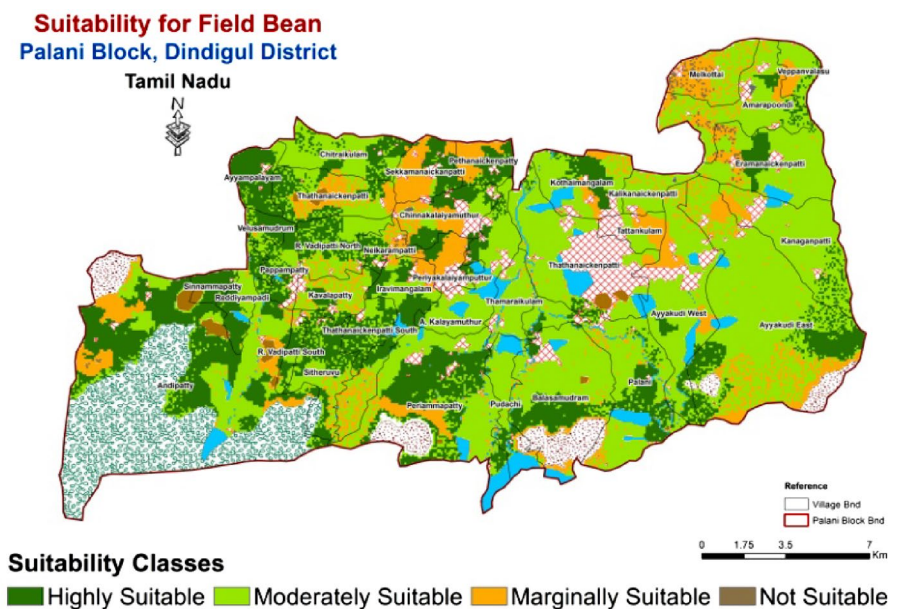
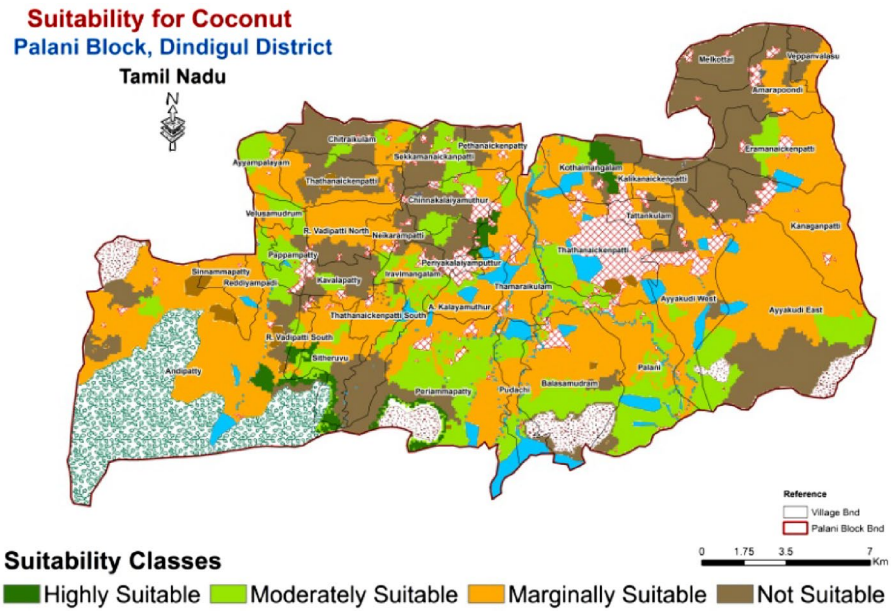


Fig. 6 Suitability map for Coconut



on experts' opinions are consistent (Kahsay et al., 2018). Relative weights calculated were used for assessing land suitability for crop cultivations as the consistency ratios are within the predefined limit of 0.1 (Saaty, 2008). For rice, the critical variables were found to be in the order of drainage > texture > slope > depth > pH. The paddy suitability analysis (Table 5) demonstrated that the majority of the area is marginally suitable (30%) for paddy cultivation, followed by the areas not suitable (19%), moderately suitable (18.2%) and highly suitable (17.9%). Soil drainage and texture were identified as the major limitations of paddy. The suitability map of paddy (Fig. 4) illustrates that the highly suitable areas for paddy fall under low-lying regions (280–300 m

MSL) i.e., alluvial soils developed from the seasonal rivers. For each crop, any specific soil or topographic parameter might be more important as pointed by Mandal et al. (2020) who mentioned that soil texture is the most important parameter in determining suitable land for wheat production.

The land suitability analysis showed that approximately 44% of the study area (17,639 ha) is moderately suitable for field bean cultivation, while 21.6% area was identified as highly suitable. Highly and moderately suitable areas were almost uniformly distributed (Fig. 5).

Results from the land suitability analysis for coconut indicated that the predominant study area is marginally suitable with the limitations of soil depth and texture. Among the

Fig. 7 Suitability map for Guava

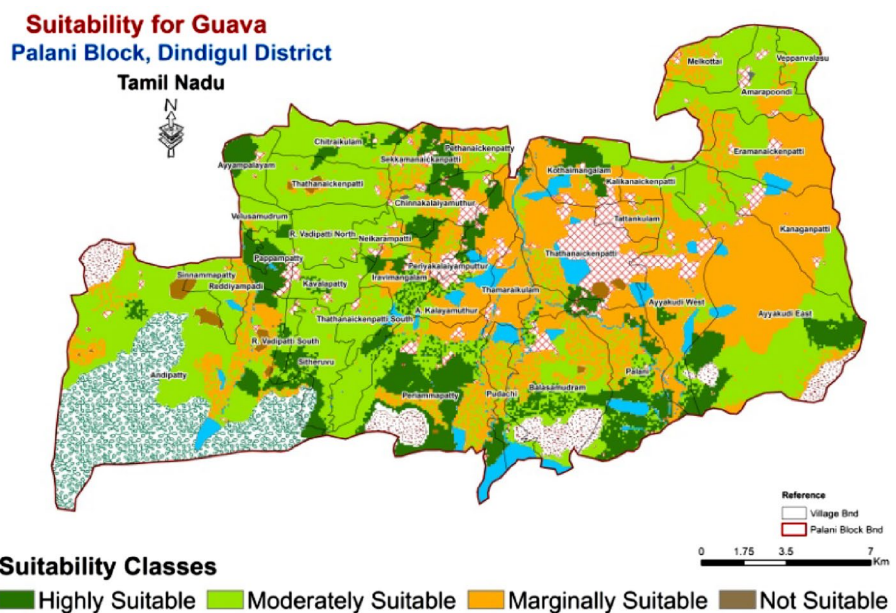


Table 5 Area and percentile area of land suitability classes for selected crops

Suitability class	Rice		Field bean		Coconut		Guava	
	ha	%	ha	%	ha	%	ha	%
Highly suitable (S1)	7186	23.4	8627	28	723	2.35	4934	16.03
Moderately suitable (S2)	4000	13	17,639	57.3	5870	19.1	14,875	48.3
Marginally suitable (S3)	12,027	39	4371	14.2	15,608	50.7	10,963	35.6
Not suitable (N)	7561	25	136	0.44	8573	27.9	2	0.01

crops considered, coconut is not suitable for the major area (21.5%) although, it is grown in the major area because of the farmers' willingness and current market scenarios. The land highly suitable for coconut cultivation is in patches covering only about 661 ha area (Fig. 6). The unsuitable lands for coconut are characterized by low soil depth, clayey texture and somewhat poor drainage.

Similar to field bean, the land suitability analysis for guava shows that the whole study area is suitable for guava cultivation, out of that 37 percent area is moderately suitable and 27 percent area is marginally suitable with minor limitations of depth and texture (Fig. 7). All the evaluated crops were found to be moderate to marginally suitable, amidst field bean and guava were suitable in a relatively high area. Shaloo et al. (2022) also demonstrated how well the AHP integrated with GIS performed in assessing the cropland suitability for wheat, sorghum, rice, pearl millet and maize considering climate, soil and topography as a primary criterion and suggested that maximum crop production can be achieved through proper utilization of lands under careful management practices.

Validation of the Land Suitability Assessment

Classification performance accuracy of the AHP–GIS method of land suitability was compared with farmers' opinions and the error matrix was tabulated. The performance of the AHP–GIS land suitability classification method was reasonably high for field beans, followed by coconut, guava and rice with kappa index of 0.64, 0.51, 0.49 and 0.40 and overall accuracy of 75%, 65%, 62% and 60%, respectively (Table 6). According to Congalton and Green (1998), the suitability classes classified with AHP–GIS are in moderate agreement (kappa index: 0.4–0.8) with the farmers' opinion.

The present study locates the prime lands suitable for paddy, field bean, coconut and guava and identifies the land that is under or over-utilized. Thus, the present study advocates that the use of combined AHP with GIS in land suitability evaluation would be advantageous for selecting suitable crops for cultivation. It delineated the degree of suitability of the major crops in each land parcel. Therefore, policy-based decisions like providing subsidies for a certain type of land use practices could be adopted to enhance productivity and sustainability. However, the reliability

(accuracy) of the land suitability analysis could be increased by the inclusion of land use land cover, climatic parameters, parent material, dynamic fertility parameters and socio-economic criteria for future studies. The multicriteria based decision making has the limitations of relying on the subjective judgements of experts rather than objective data and the importance ranking of variables may vary due to personal bias (Barakat et al., 2017). National level land suitability evaluations are being explored by many researchers envisaging that machine learning models could outperform in evaluating the land suitability for choosing the right land use to the right land (Saha & Mondal, 2022) and by, incorporating the crop yields and related indicators into land suitability models the biasness due to subjectivity will be limited. Therefore, alternate methods of assessment should also be explored before making any large-scale policy-based decisions.

Conclusion

This study employed the analytical hierarchy process (AHP) and geographic information system (GIS) to identify the lands suitable for cultivating paddy, field bean, coconut and guava in the Palani block. It aids in quick assessment of land suitability for different crops with seamless spatial information and also identifies the area that are not suitable for specific land use which would be definitely useful for selecting alternate land use and deciding suitable land management practices. The integration of AHP and GIS minimized subjectivity, and bias, and facilitated the easy integration of different databases. Our findings revealed that the majority of the study area is suitable for Guava and Field beans, while coconut cultivation, although prevalent in the region, is only marginally suitable. We uncovered key limitations such as drainage, slope and soil depth that affect the suitability of lands for paddy and coconut cultivation. This study provides valuable insights of integrating AHP and GIS in identifying priority and non-priority areas for specific crops. However, the incorporation of socioeconomic criteria in future analyses can improve the accuracy and comprehensiveness.

Table 6 Error matrix of classification

Criteria	S1	S2	S3	N	Total	Overall accuracy	Kappa index
<i>Paddy</i>							
S1	1	0	0	0	1	0.6	0.403
S2	3	3	0	0	6		
S3	1	4	7	0	12		
N	0	0	0	1	1		
Total	5	7	7	1	20		
<i>Field bean</i>							
S1	6	1	0	0	7	0.75	0.644
S2	0	4	0	0	4		
S3	0	2	5	0	7		
N	2	0	0	0	2		
Total	8	7	5	0	20		
<i>Coconut</i>							
S1	7	1	0	0	8	0.65	0.509
S2	1	4	0	0	5		
S3	0	2	1	0	3		
N	0	0	3	1	4		
Total	8	7	4	1	20		
<i>Guava</i>							
S1	4	1	0	0	5	0.6	0.461
S2	0	5	0	0	5		
S3	0	2	0	0	2		
N	1	1	2	4	8		
Total	5	9	2	4	20		

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Data Availability The data that utilized for the study available from the corresponding-author upon reasonable request.

Declarations

Conflict of interest The authors declare that they have no potential competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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