Land evaluation by integrating remote sensing and GIS for cropping system analysis in a watershed

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Quantitative land evaluation procedures, namely USDA Land Capability Classification (LCC) and FAO Land Evaluation Procedure for Soil Site Suitability for various land utilization types have been used to assess the land suitability for different crops and for generating cropping pattern for kharif (summer) and rabi (winter) seasons in a watershed. The database on soil, land use/land cover rainfall, and temperature was generated from data derived from Landsat TM remote sensing satellite and soil survey to perform an integrated analysis in the geographic information system environment. Arable and non-arable lands were delineated in the watershed using the USDA LCC and non-arable areas were masked for removal from future analysis. Different land quality parameters, viz. soil texture, depth, erosion, slope, flooding and course fragments under various land units were evaluated for a number of crops. Subsequently all of them were integrated using a sequence of logical operations to generate the land suitability maps for various crops. Kharif and rabi season cropping patterns were developed by integrating crop suitability maps for the winter and summer seasons separately. Finally, cropping system maps for the watershed were obtained by integrating the two season cropping sequences within the crop calendar. Results indicated that the present agricultural area of 47% could be increased to 71% by adopting scientific land evaluation methods for watershed development. It was also found that better land-use options could be implemented in different land units as the conventional land evaluation methods suffer from limitation of spatial analysis for the suitability of various crops.

Keywords: Cropping system, geographical information system, land evaluation, remote sensing.

LAND evaluation using a scientific procedure is essential to assess the potential and constraints of a given land parcel for agricultural purposes[1]. In the recent past, the ill-effects of land use on the environment and environmental sustainability of agricultural production systems have become an issue of concern. The problems of declining soil fertility, stagnant yield level and unfettered soil erosion are associated with intensive agriculture in industrialized countries, while over-exploitation of natural resources and scarcity of inputs like chemical fertilizers denote intensive agriculture in the developing areas[2,3]. Land evaluation and crop suitability analysis would resolve these issues while providing better land-use options to the farmers. It is known that continuous practice of one cropping system type would lead to deteriorating soil health and reduce soil resilience for maintaining productivity by evolving soil allelopathic or growth of deleterious microorganisms in the soil. This causes yield decline, which cannot be improved with the application of mineral fertilizers[4]. Hence analysis of crop suitability under various systems that could be grown in a given area is essential. Remote sensing (RS) data are used for estimating biophysical parameters and indices besides cropping systems analysis, and land-use and land-cover estimations during different seasons[5,6]. However, RS data alone cannot suggest crop suitability for an area unless the data are integrated with the site-specific soil and climate data. RS data can be used to delineate various physiographic units besides deriving ancillary information about site characteristics, viz. slope, direction and aspect of the study area. However, detailed information of soil profile properties is essential for initiating crop suitability evaluation. Hence, soil survey data are indispensable for generating a soil map of the given region, which helps in deriving crop suitability and cropping system analysis.

RS data coupled with soil survey information can be integrated in the geographical information system (GIS) to assess crop suitability for various soil and biophysical conditions. The present study was undertaken to demonstrate the usefulness of RS and GIS technologies coupled with soil data to assess crop suitability in order to implement sustainable cropping systems in a watershed. The potential of the integrated approach in using GIS and RS data for quantitative land evaluation has been demonstrated earlier by several researchers[7,8]. Therefore, the objective of this study was land evaluation using RS and GIS environments, to suggest suitable cropping patterns for a watershed area.

A watershed comprising an area of 15,000 ha in Dehradun District, Uttarakhand, India, situated at 77°45′22″–78°00′00″E long. and 30°20′00″–30°28′21″N lat. was selected for land evaluation and cropping system suitability analysis. The watershed is characterized by subtropical to semihumid climate[9]. The mean annual temperature ranges from 30.85°C in summer to 15.22°C in winter, with a mean annual rainfall of 1700 mm. The landform was delineated into lower Himalayan mountains in the north and alluvial plains in the south, with sloppy terrain. The land use is dominantly under forest and further delineated into dense, moderately dense and degraded forests having sal (*Shorea robusta*), pine (*Pinus roxburghii*), sisham (*Dalbergia sissoo*), and shrubs like *Lantana camara*, *Agava sissiliva* mixed with *Saccharum spontaneum*, and *Cynoden dactylon* grasses. The perennial source of water for the main river in the study area, the Suarna river,

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comes from the snowmelt in the higher Himalayan mountains. In the upper and middle piedmont areas irrigation is provided through channels constructed to divert the snowmelt water for agriculture. Paddy, wheat, mustard, maize, and sugarcane are some of the dominant crops in the watershed, in addition to mango (*Mangifera indica*) and leechi in some areas of piedmont plains.

False colour composite was generated using digital data of Landsat TM bands 5, 3, 2 to perform landform analysis and delineate different landforms and land-use classification through image processing. Land-use and land-cover classification was performed by supervized classification, maximum likelihood classifier using suitable filters. The classified land-use classes are presented in Table 1. Survey of India (SOI) toposheet (53 F/13) at 1 : 50,000 scale was used to prepare a base map of the study area for soil survey and field work, and a contour map to derive slope, aspect maps of the study area. Integrated Land and Water Information System (ILWIS) was used to perform the spatial analysis and data integration.

Physiography map of the watershed was prepared using the information derived from satellite data, topographic features and ground truth collected during the field work[10]. Based on the variations in the image characteristics and watershed terrain variability, the study area was divided into four landforms, namely mountains (M), upper piedmonts (P), top uplifted terraces (T), and river terraces (AT). These landforms are further subdivided into 13 physiographic units based on the elevation, slope direction and gradient, aspect (Table 2) to generate the final physiography map in GIS. Soil survey was conducted in all the physiographic units, and soil pedons were examined and described according to the methods given in the Soil Survey Manual[11]. Soil samples from all diagnostic horizons of the typical pedons were collected to determine the physico-chemical properties of the soils. The soils were classified and mapped[12] and the soil map was also generated in GIS. Soil associations mapped in different physiographic units are presented in Table 3. The attribute data of all the pedons were also generated in GIS for data integration and overlay analysis.

Table 1. Spatial extent of different land use/land cover classes of the study area by supervized classification of Landsat TM bands 5, 3, 2 data

Land use/cover	Area (ha)
Dense forest (*Shorea robusta*)	1619.19
Dense forest (mixed)	143.73
Moderately dense forest	2881.17
Degraded forest	1835.46
Cultivation (dominantly wheat)	4541.31
Cultivation (dominantly sugarcane, maize)	1429.11
Horticulture plantations (mango)	33.66
Scrub lands	512.73
Settlements	478.89
River course	1321.56

Land Capability Classification (LCC) method developed by the United States Department of Agriculture (USDA) was used in the study to estimate different land capability classes in the watershed[13]. This method provides information to farmers on the most appropriate use of the farm lands to obtain maximum benefits. The first four classes are arable lands with some limitations in soil conservation and crop management practices[14]. Different soil mapping units in the watershed were evaluated for three levels of land capability classification such as order, class and sub-class for different land qualities such as soil texture, slope, drainage, depth, erosion hazard, and flooding hazard. Different maps were also generated for evaluating these land qualities. These maps were used in 'Logical operator' of 'Map Calc' in GIS to classify the above land-quality maps according to their suitability in land capability classes from I to VIII. Limitations in each mapping unit were are also recorded and tabulated in attribute tables. Finally all the these land-quality maps were integrated to generate the land capability class of a mapping unit using Max operator in 'Map Calc' module; this gave the classified land capability map of the study area (Figure 1). Arable (agriculture) and non-arable (non-agricultural) areas in the watershed were delineated by crossing the soil map with LCC map in 'Cross' operation. New attribute tables were also created to store the new spatial data pertaining to different land units of arable areas and subsequently used for land utilization type (LUT) evaluation and cropping system analysis.

Important crops dominantly grown in the watershed, such as LUT-I (paddy), LUT-II (wheat), LUT-III (maize), LUT-IV (mustard) and LUT-V (sugarcane) were chosen for land evaluation for each soil unit using the FAO framework of land evaluation[15]. The deterministic land qualities like soil texture, soil depth, drainage, erosion, coarse fragments and flooding as given in Table 4, were selected to assess the suitability for a given LUT in each mapping unit. The methodology used for the analysis is presented in Figure 2. It may be seen from Figure 2 that in the second stage, each land quality (LQ) suitability map has been integrated to generate the LUT map of a given crop using land utilization criteria and suitability ratings for the crop in map calculation module. In the third stage, integration and reclassification of each land quality with each LUT was done to generate the suitability maps in Max operation module. Kharif and rabi season suitability maps were generated separately by further integrating the respective crops grown in both seasons using cross operation in ILWIS. The cropping pattern map for the calendar year was generated by integrating kharif and rabi season suitability maps, and attribute tables for kharif and rabi suitability maps were also generated.

The watershed area is characterized by diverse terrain characteristics of the low Himalayan mountains in the north and sloppy alluvial plains composed of alluvial and colluvial materials in the south. Table 3 shows that the

Table 2. Soil and land characteristics of the mapping units in the watershed

Soil physio-graphic unit	Texture	Soil depth	Slope (%)	Erosion	Drainage	Flooding hazard	Coarse fragments (%)	Moisture availability
M11	Loamy skeletal	Very deep	25–50	Moderate	Well	Very low	>35	Low
M12	Loamy skeletal	Very deep	25–50	Low to moderate	Well	Very low	35	Low to moderate
M21	Loamy skeletal	Very deep	25–50	Moderate	Well	Very low	35	Low
M22	Loamy skeletal	Very deep	25-50	Low	Well	Very low	35	Low
P11	Fine loamy	Very deep	1–5	High	Well	Very low	<35	Low
P12	Fine loamy	Very deep	1–5	Moderate	Well	Low	<35	Low
P21	Fine loamy	Very deep	1–5	Low	Well	Low	<35	Moderate
P22	Fine loamy	Very deep	1–5	Moderate	Well	Low	<35	Low
T1	Fine loamy	Very deep	<3	Slight to moderate	Well	Very low	<35	Low to moderate
T2	Fine loamy	Very deep	15–25	Moderate	Excessively well-drained	Very low	<35	Low
AT1	Course loamy	Very deep	<3	Slight	Moderately well-drained	Moderate	<35	Moderate
AT2	Fine loamy	Very deep	<3	Slight	Well-drained	Low to moderate	<35	Moderate
AT3	Fine loamy	Very deep	<3	Slight	Well-drained	Low	<35	Low to moderate

Table 3. Brief description of the physiographic and soil units of the watershed

Physiography	Soil association	Area (ha) (%)
Mountains (north aspect) open: M11	Loamy skeletal, Dystric Eutrudepts Loamy skeletal, Typic Udorthents	624 (4.1)
Mountains (south aspect) cultivated: M12	Loamy skeletal, Typic Eutrudepts Fine loamy, Dystric Eutrudepts	52 (0.3)
Mountains (south aspect) forest: M21	Loamy skeletal, Mollic Hapludalfs Coarse loamy, Lithic Udorthents	586 (3.8)
Mountains (south aspect) open: M22	Loamy skeletal, Dystric Eutrudepts Coarse loamy, Lithic Udorthents	633 (4.1)
Upper piedmont (more eroded): P11	Loamy, Dystric Eutrudepts Loamy skeletal, Dystric Eutrudepts	2611 (17.1)
Upper piedmont (less eroded): P12	Fine loamy, Typic Hapludalfs Coarse loamy, Typic Udifluvents	539 (3.5)
Lower piedmont (more eroded): P21	Fine loamy, Dystric Eutrudepts Loamy skeletal, Dystric Eutrudepts	640 (4.2)
Lower piedmont (less eroded): P22	Fine loamy, Mollic Hapludalfs Fine loamy, Dystric Eutrudepts	955 (6.3)
Top uplifted terraces: T1	Fine loamy, Typic Hapludalfs Fine loamy, Mollic Eutrudepts	2229 (14.9)
Slide sloping uplifted terraces: T2	Fine loamy, Dystric Eutrudepts Loamy skeletal, Typic Eutrudepts	1685 (11.1)
River terraces (lower): AT1	Coarse loamy, Aquic Eutrudepts Loamy skeletal, Typic Eutrudepts	364 (2.4)
River terraces (middle): AT2	Fine loamy, Mollic Hapludalfs Fine loamy, Dystric Eutrudepts	1905 (12.5)
River terraces (upper): AT3	Fine loamy Typic, Hapludolls Loamy skeletal, Typic Eutrudepts	1253 (8.2)

dominant soils in the watershed belong to Inceptisols (77%) followed by Entisols (15.5%) and Mollisols (7.5%) in different soil units. The soil texture is loam to fine loam and skeletal material is also prominent.

Four major LCC classes were delineated in the study area (Table 5) using the USDA methodology performed in GIS. The results show that soil erosion is the major limitation in all the classes besides other limiting characteristics such as wetness and soil depth. Classes III and IV occupied 4083.1 and 4967.1 ha of area respectively, where surface soil texture and slope are the second-level limitations. The land-use/land-cover data show that about

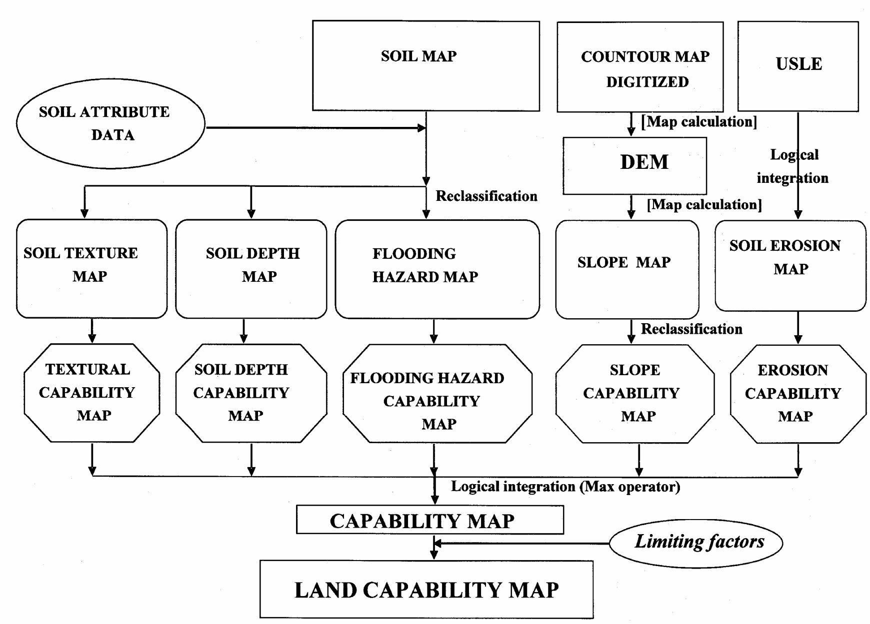

Figure 1. USDA land evaluation method performed in GIS.

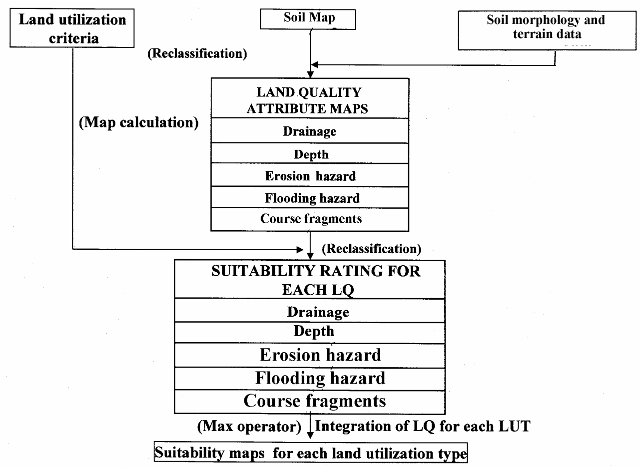

Figure 2. Soil and land suitability for each LUT based on FAO land evaluation model.

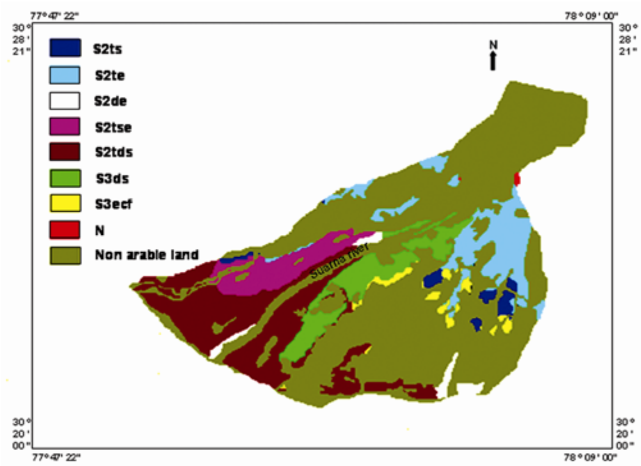

Figure 4. Suitability of paddy in different land units.

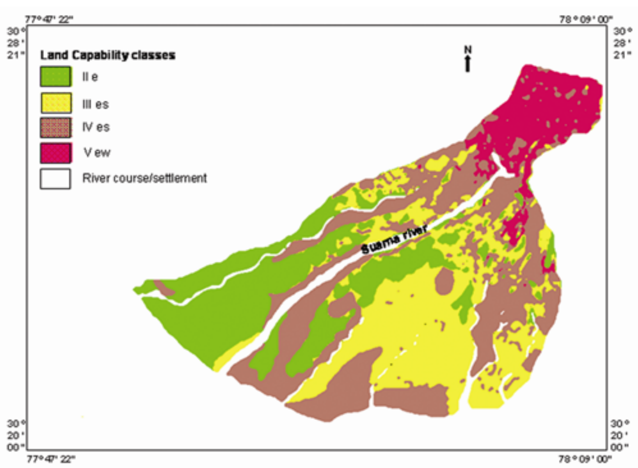

Figure 3. Land capability classes of the watershed.

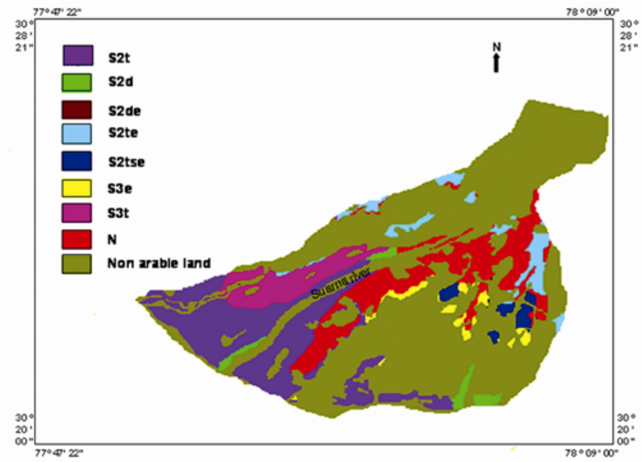

Figure 5. Suitability of wheat in different land units.

Table 4. Criteria and ratings of soil and land qualities for five land utilization types (LUTs)

Soil and land quality	Suitability class	LUT-I (paddy)	LUT-II (wheat)	LUT-III (maize)	LUT-IV (mustard)	LUT-V (sugarcane)
Texture	S1	CL	L	SL	SL	CL
	S2	SL	SL	L	CL	SC
	S3	Coarse SL	LS	CL	SC	C
	N	S	Fragmental	S	S	S
Soil depth	S1	Deep	Very deep	Deep	Deep	Very deep
	S2	Moderate	Deep	Mod deep	Mod deep	Deep
	S3	Shallow	Mod deep	Shallow	Shallow	Mod deep
	N	Very shallow	Shallow	Very shallow	Very shallow	Very shallow
Drainage	S1	Imperfectly to poor	Well-drained	Well-drained	Well-drained	Well-drained
	S2	Moderate to well-drained	Mod well-drained	Mod well-drained	Mod well-drained	Mod well-drained
	S3	Somewhat excessively	Imperfectly drained	Imperfectly drained	Imperfectly drained	Imperfectly well-drained
	N	Excessively drained	Poorly drained	Poorly drained	Poorly drained	Poorly drained
Slope	S1	Level	Flat to level	Nearly level	Nearly level	Level
	S2	Very gentle	Gentle slope	Mod sloping	Very gentle	Very gentle
	S3	Gentle slope	Mod slope	Mod steep	Mod to strong slopping	Gentle slopping
	N	Moderate to steep	Steep to very steep	Steep to very steep	Steep Slopping	Steep Slopping
Erosion	S1	None	Slight	None	Very low	None
	S2	Slight	Moderate	Slight	Low	Slight
	S3	Moderate	High	Moderate	Moderate	Moderate
	N	Severe	Severe	Severe	Severe	Severe
Coarse fragments	S1	None	None	None	None	None
	S2	Slight	Slight	Slight	Slight	Slight
	S3	Moderate	Moderate	Moderate	Moderate	Moderate
	N	Severe	Severe	Severe	Severe	Severe
Flooding fragments	S1	Very low	Very low	None	Very low	None
	S2	Medium	Low	Low	Low	Low
	S3	High	Moderate	Moderate	Moderate	Moderate
	N	Very high	Severe	High	Severe	High

SL, Sandy loam; CL, Clay loam; L, Loam; LS, Loamy sand; S, Sand, S1, Highly suitable; S2, Moderately suitable; S3, Marginally suitable and N, Not suitable.

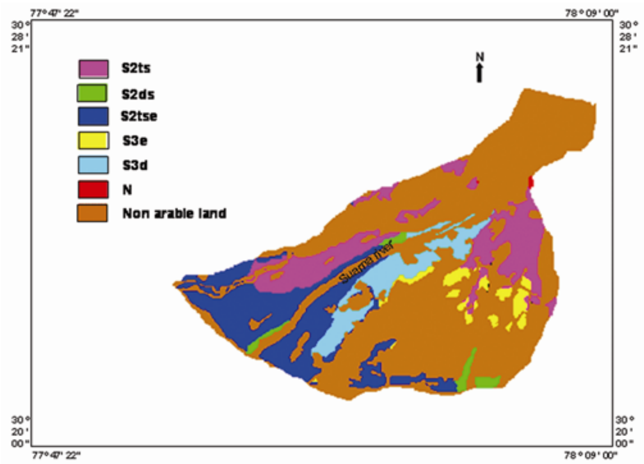

Figure 6. Suitability of wheat in different land units.

Table 5. Land capability classes in the study area

Class	Sub-class	Area (ha)
II	II e	3571.83
III	III es	4083.10
IV	IV es	4967.10
V	V es	1462.50

47% area is under forest cover and non-agricultural, but the land capability analysis showed that 10,700 ha (71%) area is suitable for agriculture (Figure 3). This indicates that more area can be brought under cultivation with improvement in soil conservation and management practices.

Crop suitability analysis (Table 6) clearly demonstrated that the low mountains with northern and southern aspects

Table 6. Soil suitability of mapping units for different land utilization types

Mapping unit	Rabi season: Wheat	Mustard	Sugarcane	Suitability	Kharif season: Paddy	Maize	Sugarcane	Suitability
M11	N	N	N	N	N	N	N	N
M12	N	N	N	N	N	N	N	N
P11	S3e	S3e	N	Wheat, mustard	S3e	S3ecf	N	Paddy, maize
P12	S2tse	S3e	S3et	Wheat, mustard, sugarcane	S3e	S2ts	S3et	Paddy, maize, sugarcane
P21	S3t	S2se	S3e	Mustard, wheat	S2tse	S2ts	S3e	Paddy, maize, sugarcane
P22	S3t	S3e	S3e	Mustard, wheat	S2ts	S2tse	S3e	Paddy, maize, sugarcane
T1	S2te	S2te	S2e	Mustard, wheat	S2ts	S2te	S2e	Paddy, maize, sugarcane
T2	N	S3dse	N	Mustard	S3d	S3ds	N	Paddy, maize
AT1	S2d	S2ef	S2ed	Wheat, mustard, sugarcane	S2ds	S2de	N	Paddy, maize, sugarcane
AT2	S2t	S2ef	S2e	Wheat, mustard, sugarcane	S2tse	S2tds	S2e	Paddy, maize, sugarcane
AT3	S2t	S2ef	S2e	Wheat, mustard, sugarcane	S2tse	S2tds	S2e	Paddy, maize, sugarcane

E, Erosion; cf, Course fragments; t, Texture; d, Drainage; s, Slope; f, Flooding and N, Not suitable.

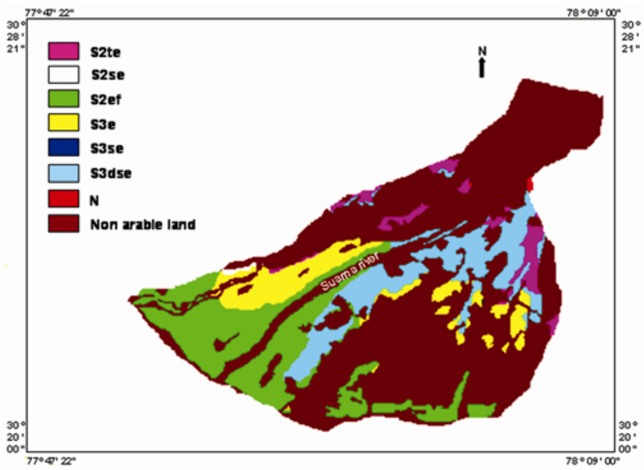

Figure 7. Suitability of wheat in different land units.

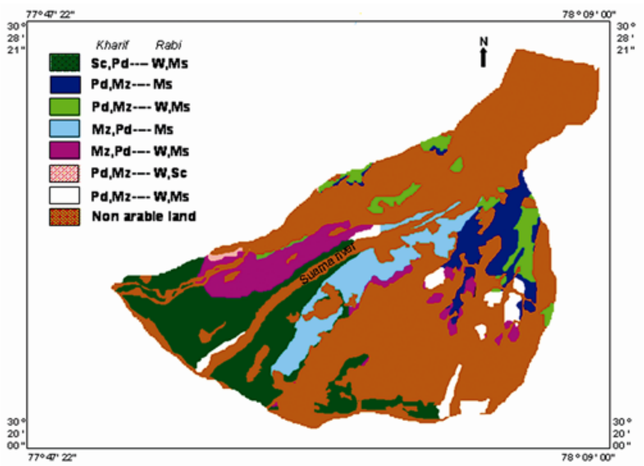

Figure 8. Cropping system for kharif and rabi seasons in different land units in watershed (Pd, Paddy; W, Wheat; Mz, Maize; Ms, Mustard and Sc, Sugarcane).

were not suitable for paddy cultivation (Figure 4). The upper piedmont (P11) area showed limitation of erosion. The remaining soil units were found to be suitable with minor limitations in texture, drainage and slope for paddy cultivation. Uplifted terraces (side slopes, T2) were not found suitable for wheat (Figure 5). The upper piedmont (P11 and P12) showed major limitations for wheat cultivation. Maize and mustard were found suitable in maximum number of mapping units with minor limitations (Figures 6 and 7) respectively. Sugarcane cultivation showed severe limitations in the upper piedmont (P11) and was not suitable in the side slopes of the uplifted terraces. Forest plantation is recommended in mapping units M11 and M12, as they were not found suitable for any LUT.

The crop suitability analysis results showed that the wheat–paddy sequence was suitable in the upper and lower piedmonts and the alluvial plain in the watershed (Figure 8). In the lower piedmont areas mustard–maize sequence was found suitable. Paddy is suggested in some uplifted terraces where flooding is a limitation for cultivation of other crops. In the remaining uplifted terraces and alluvial plains, sugarcane–paddy was found as a suitable sequence for sustainable production. Overall examination of different suitability combinations showed that wheat and mustard in addition to sugarcane were found better for rabi season over other rabi crops. Similarly, in the kharif season paddy, maize and sugarcane were suitable. It is estimated that wheat–sugarcane in rabi season and sugarcane–paddy in kharif season are expected to occupy a net sown area of 2359.5 ha in the watershed in both seasons. Similarly, wheat–mustard and paddy–maize occupy 1776.3 ha area in rabi and kharif seasons.

The results demonstrate that the available RS satellite data in collaboration with soil survey data can be best utilized for agricultural development of an area with special reference to the mountainous areas, where acquiring the soil and land-use/land-cover data remains a difficult task. Multiple integration options in GIS are of immense use for data integration and overlay analysis to obtain better and faster results in judicious utilization and allocation of natural resources. It has been also found that the present land-use options can be changed to profitable ones for better economic returns and sustainable resource management of the given land, which could not have been possible through conventional land evaluation methods.

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Comparison of floristic diversity of evergreen forest inferred from different sampling approaches in the Eastern Ghats of Tamil Nadu, India

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Floristic inventory and diversity studies are conducted using various sampling methods. The present study compared floristic diversity of an evergreen forest of Kolli Hill based on three sampling methods, viz. (a) ad hoc (AH) vegetation survey, (b) stratified random plot (SRP) and (c) bigger plot (BP). The evergreen forest area (2889.5 ha) was classified with IRS 1D LISS III satellite data and the evergreen area belonging to different reserve forests were subset. Floristic inventory with SRP was carried out on 0.1% of total evergreen area using 20 × 20 m plot. An earlier study done on the same locality was considered as the BP. The AH, SRP and BP recorded, 121, 91 and 78 tree species respectively. The mean tree densities were 547 and 478 trees ha^{-1} and the mean basal areas were 46.74 and 43.6 m^2 ha^{-1} in SRP and BP respectively. All the diversity indices calculated based on SRP with 3 ha sampling area and BP with 8 ha sampling area varied considerably.

Keywords: Diversity indices, evergreen forest, floristic diversity, sampling techniques.

FLORISTIC inventory and diversity studies help us understand the species composition and diversity status of forests[1], which also offer vital information for forest conservation[2]. Quantitative inventories, moreover, help identify species that are in different stages of vulnerability[3] as well as the various factors that influence the existing vegetation in any region[4]. However, the efficacy of inventory studies depends critically on the selection of an appropriate sampling technique[5].

Floristic inventory and diversity studies are carried out following many sampling techniques such as random plots of various dimensions and sizes, viz. Whittakar and Niering[6], and Devi and Yadava[7] (10 × 10 m), Gillespie *et al.*[8] (2 × 50 m), Huang *et al.*[9] (50 × 20 m), random strip plots[3] of 2 × 50 m and 6 × 50 m, bigger plots[10] of 50 ha

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