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Land productivity and site-suitability assessment for crop diversification using remotely sensed data and GIS techniques

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Abstract: A watershed in Shiwalik hills of Himachal Pradesh was delineated into three major physiographic units *i.e.* Shiwalik foot hills, piedmonts and flood plains which consisted of eighteen soil mapping units identified through remote sensing technique. These soils belong to three orders *viz.,* Entisol, Inceptisol and Alfisol. Storie's index showed 4.45, 8.29 and 15.45% of total geographic area (TGA) of the watershed under fair, poor and very poor land productivity classes, respectively, whereas, considerable area (13.18%) was found to be under non-agricultural class. About 8.56% of TGA was highly suitable for wheat and maize crops whereas 74.94% was permanently not suitable for these crops. Similarly 8.56% area was found moderately suitable for tomato and pea cultivation, whereas 82.57 and 79.88% of TGA was found permanently not suitable for these crops. As regards mango, 8.56, 8.70, 25.16 and 53.80% of TGA was highly suitable, marginally suitable, not suitable temporarily and not suitable permanently. Soil-site suitability analysis for important multipurpose tree species indicated three categories for khair (*Acacia catechu*) *viz.,* highly suitable, moderately suitable and marginally suitable covering 20.50, 50.11 and 25.61% of TGA whereas, four categories of suitability were identified for safeda (*Eucalyptus teriticornis*) comprising highly suitable, marginally suitable, not suitable temporarily and not suitable permanently and covered 8.56, 12.00, 21.86 and 53.80% of TGA, respectively.

Additional keywords: *Shiwalik hills, watershed, soil suitability, crop diversification*

Introduction

Prevailing climate (rainfall and temperature) within a region plays a central role in dictating plant species composition, productivity and the dynamics of populations over time while soils and topography exert a strong influence on spatial patterns of plant distribution, growth and abundance over the landscape through regulation of moisture and nutrient availability. Himachal, being a hilly state, with wide variations in physiography, geology and climate occurring at close intervals, offers wide scope for cultivation of various types of crops. However, since each plant species requires specific soil and climatic conditions for its optimum growth, economic production of these crops requires identification of factors limiting the productivity and adoption of suitable practices to rectify them. As such, assessment of productivity of land and generating precise information related to its suitability for the cultivation of different crops becomes a pre-requisite for general land use and efficient crop planning in the area. Several approaches of land productivity assessment like Land Capability Classification (Klingebiel and Montgomery 1961) and Framework of Land Evaluation (FAO 1976; 1993) have been used widely through remote sensing techniques. However, Storie's Index of soil productivity rating (Storie 1978) has been evaluated only by few researchers using remote sensing data (Saxena *et al.* 1985; Malla 1992; Kudrat and Saha 1993). Further, soil-site suitability evaluation is one such approach used to determine the potential of land for site- specific crop planning by integrating soil characteristics with climate and land use. Moreover, such information is known to improve usefulness of soil survey reports which otherwise lack wider acceptability.

In mid hill zone of Himachal Pradesh, tomato (*Lycopersicon esculentum* Mill.) and pea (*Pisum sativum*) are being cultivated as off-season crops (tomato as *kharif* and pea as *rabi*). Average yields are good (30 t ha^{-1} in case of tomato and 13 t ha^{-1} in case of pea) and the proposition is quite remunerative. However, the scenario in Shiwalik foot hills of the state is different where yield levels are very poor. Mango *(Mangifera indica)* is another important horticultural crop which can be successfully cultivated in the area. Khair *(Acacia catechu)* and safeda *(Eucalyptus teriticornis)* are two important multipurpose tree species of Shiwalik hill region of the state that are planted on farm boundaries, as block plantations and as components of agro-forestry systems. These provide supplementary income through timber, fuel wood, by-product development and also improve soil fertility through nutrient cycling. Wheat *(Triticum aestivum)* is an important cereal crop grown in the region followed by maize *(Zea mays)*. Low productivity of these crops can be attributed partly to lack of knowledge about proper soil-site suitability and desired management levels. The present study envisages the potential utility of soilscape information derived from remote sensing data in combination with terrain information (generated from topographical maps) and the soil characteristics, for assessing productivity and agro-climatic as well as agro-edaphic suitability of land for commonly grown crops and mapping the same with a view to tap the potential of varied soil -site conditions of the area.

Materials and Methods

Study area, data used and methodology

The watershed situated in Shiwalik hills of Solan district in Himachal Pradesh is located between 30^0 53 45′ to 30^0 56 15′ N latitudes and 76^0 50′ to 76^0 54′ E longitudes and cover an area of 1453.53 ha in Survey of India toposheet 53 F/13. Physiographically, the study area represents lower Shiwalik hills of Himalayan region. The climate of the area is sub-humid sub-tropical. Mean winter and summer months temperatures are 18 and 25 ^{0}C, respectively and highest is observed in the month of June. The winters are generally too cold. Precipitation is mainly concentrated (about 80%) in monsoon months *i.e.* mid June to mid September. Monsoon rains in the area are heavy and intense. Average annual rainfall is about 1100 mm. The area has mostly udic moisture and hyperthermic temperature regimes. The cultivated land is both irrigated (18%) and rainfed (82%). The rainfed areas are poorly maintained. On an average, each household maintains 4-6 livestock heads. The dominant natural vegetation consists of mixed deciduous forests of khair *(Acacia catechu)*, kikar *(Acacia nilotica)*, bamboo (*Dendrocalamus strictus*), amaltas (*Cassia fistula*), shisham *(Dalbergia sissoo)*, neem *(Azadirachta indica)*, palas *(Butea monosperma)* as the main tree species alongwith basuti *(Adhatoda vasica)*, karonda *(Carrisa spinarum)*, sentha *(Dodonaea viscosa)*, ak *(Ipomea carnea)*, ber *(Zizyphus jujuba)* and bana *(Vitex negundo)* as main shrubs. The grasses like spear (*Heteropogon contortus)*, bhabbar (*Eulaliopsis binata*), dhaulu (*Chrysopogon fulvus) etc.* occupy wastelands and scattered fruit trees like mango (*Mangifera indica*), papaya (*Carica papaya*), citrus (*Citrus spp.) etc.* alongwith fodder trees such as bihul (*Grewia optiva)*, mulberry *(Morus alba)*, kachnar *(Bauhinia variegata)* and khirak (*Celtis australis) etc.* occur on field bunds.

Base map was prepared from SOI topographical sheet 53F/13 (1: 50,000). The geo-coded PAN and FCC imagery of IRS-LISS III (November 10, 2001) was visually interpreted supported by ground truth verification to prepare physiographic-soil association map. Detailed soil survey of the watershed was conducted to study the spatial distribution of soils on 1:12,500 scale. This was accomplished by preparing physiographic cum landuse map and then by associating soil composition for each classified physiographic-landuse unit. Soil composition of physiographic-landuse units of the watershed were found out by carrying field soil survey in sample strips and by collecting data on soil characteristics from soil profiles, minipits and auger bores supplemented with laboratory data. In all, thirty two profiles were exposed and horizon-wise soil samples collected from the study area. The soils were classified as per the Soil Taxonomy

(Soil Survey Staff 1998).

Land productivity assessment

Storie's index of productivity is a function of four major factors *viz.*, A-rating on the basis of general character of soil profile reflecting soil development, B-rating on the basis of soil texture, C-rating on the basis of slope of the land and X-rating on the basis of conditions other than A, B and C like soil reaction, drainage, erosion, fertility status *etc.* Land productivity (LP) index was calculated as follows:

LP = (A/100) X (B/100) X (C/100) X (X/100) X 100

Finally, lands were graded into six groups on the basis of LP ratings as excellent (LP=80-100), good (LP=60-79), fair (LP=40-59), poor (LP=20-39), very poor (LP=10-19) and not suitable (LP<10).

Soil suitability assessment

The soils have been evaluated to assess their suitability for major crops following the method developed by FAO (1976, 1993). This method is based on comparison of plant growth and production requirements with prevailing environments and involves four levels of classification: *i)* order reflecting kind of suitability like suitable (S), and not suitable (N); *ii)* class- reflecting degree of suitability like highly suitable (S1) *i.e.* lands having no significant limitations or slight limitations causing low severity; moderately suitable (S2) *i.e.* lands having moderate limitations or aggregation of slight limitations causing moderate severity; marginally suitable (S3) *i.e.* lands having aggregation of severe limitations; currently not suitable (N1) *i.e.* lands having limitations which cannot be corrected by accepted methods and lands permanently not suitable (N2); *iii)* sub class- reflecting kind of limitations within the classes and *iv)* unit- reflecting minor differences in a required management within sub-class (Dent and Young 1981). The climatic and land quality requirements of crops at different levels of limitations were compared with available data (Sehgal 1986) and each mapping unit was evaluated by number and kind of limitations ranging from 0 to 4 *i.e.* none to very severe limitation as per table 1. Various soil-site characteristics used for such comparisons included data on mean annual rainfall, temperature, slope, drainage, flood hazards, erosion, soil depth, soil texture, stoniness, relief, NPK status, pH and base satuaration percentage (BSP). While drainage was well, temperature, rainfall, flood hazards, relief, pH and BSP offered none or slight limitations for the crops under study. As such, these parameters were dropped during final suitability assessment. Suitability Index (SI) was calculated as:

SI = % area in suitability class X productivity potential*

(*0.85 for suitable, 0.6 for moderately suitable, 0.4 for marginally suitable, 0.2 for not suitable)

All soil resource and suitability maps were generated at scale 1:12,500 using GIS system ARC/INFO Workstation (version 7.4) of ESRI (Environment System Research Institute, Redland California USA).

Results and Discussion

Physiography, land use and soils

Physiography-cum-land use-soil (mapping units) details of the watershed (Table 2) and the map prepared after interpretation of satellite imagery in conjunction with field checks is presented as figure 1A. The soil properties are presented in table 3 and figure 1B. The mapping units falling under three major physiographic positions *i.e.* Shiwalik foot hills, piedmonts and flood plains were delineated and mapped.

Shiwalik foot hills (H)

This unit represents Shiwalik and residual foot hills. It is complex physiographic unit in the area covering a substantial part of the watershed (975.69 ha) amounting to 67.12% of the total geographical area (TGA) of the watershed. It is further divided into upper Shiwalik foot hills (H1) representing the area 600 m above msl (above 25% slope) and lower Shiwalik foot hills (H2) representing area between 500-600 m and slope (10-35%). In some areas, however, slopes above 50% are also encountered.

The H1unit is further divided into three mapping subunits *i.e.* H11 (higher altitudes having mixed dense forests), H12 (lower altitudes having mixed dense forests) and H13 (sparse forests); H2 unit is further divided into five subunits *i.e.* H21 (mixed dense forests), H22 (sparse forests), H23 (agriculture), H24 (scrub land) and H25 (grassland) on the basis of dominant land use.

Entisols are dominant on upper Shiwalik foot hills and these soils are very shallow to slightly deep, well drained, light textured associated with moderate to severe erosion,

Table 1. Criteria used for rating soil- site suitability for different crops

Soil - site characteristics	Degree of limitation				
	0 (None)	1 (Slight)	2 (Moderate)	3 (Severe)	4 (Very severe)
Rain fall (mm)	>1000^{WTPM},>500^{E},>750^{KMz}	250-500^{E},500-750^{KMz}, 750-1000^{WTPM}	150-250^{E},250-500^{KMz}, 00-750^{WTPM}	<150^{E},<250^{KMz}, <500^{WTPM}	-
Temp. (^{0}C)- during growing period	18-24^{Mz},18.5-26^{T}, 10-18^{P}, 24-30^{M},15-18^{WE},22-26^{K}	26-30^{TK}, 18-22^{PWE}, 30-40^{M},24-27^{Mz}	30-33^{T},22-26^{P},>22^{WE}, 40-48^{M},27-30^{Mz},30-36^{K}	33-40^{T}, 26-29^{P}, >48^{M},>30^{Mz},36-40^{K}	>40^{T}, >29^{P}
Slope (%) - Plain irrigated	<1^{WMzTP}	1-3^{WMzTP}	3-8^{WMz},3-5^{TP}	>8^{WMz},5-10^{TP}	>10^{TP}
-Hilly unirrigated	<3^{WMzTPM},<8^{EK}	3-8^{WMzTP}, 3-15^{M},8-15^{EK}	8-15^{WMzTP},15-30^{MEK}	15-25^{WMzTP},>30^{MEK}	>25^{WMz}
Drainage	Well^{all}	Moderately well^{all}	Imperfect^{all}	Poor^{all}	Very poor^{all}
Flood hazards	Nil^{WMzKTP}, Nil to slight^{ME}	Slight^{WMzKTP}, Moderate^{ME}	Moderate^{WMzKTP}, Severe^{ME}	Severe^{WMzKTP}, Very severe^{ME}	Very severe^{WMzKTP}
Erosion	None^{WMzETPM}, None to slight^{K}	Slight^{WMzETPM}, Moderate^{K}	Moderate^{WMzETPM}, Severe^{K}	Severe^{WMzETPM}, Very severe^{K}	Very severe^{WMzETPM}
Soil depth (cm)	>80^{WP}, >100^{MzKT}, >150^{EM}	80-100^{MzT}, 50-80^{WP}, 50-100^{K},100-150^{M}, 80-150^{E}	50-80^{MzTE}, 30-50^{KP},	30-50^{MzT}, 15-30^{P}, 20-50^{W},50-100^{M}	<30^{MzT}, <15^{P}, <25^{ME}, 25-50^{ME}, <20^{W},<30^{K}
Soil texture	(sil,l,sicl,fsl,cl)^{TP}, (sil,sicl,cl)^{W}, (sil,sicl,cl,l)^{Mz}, (sil,l,fsl,cl)^{MKE}	(scl,sc,sl)^{TP},(sc,scl,l,sl)^{W}, (csl,sc,sicl)^{KME}, (sic,c,sc,scl,sl)^{Mz}	(sic,c,ls)^{WTP},(ls)^{Mz}, (sic,sc,ls)^{E},(c,s)^{K} (sic,ls)^{M}	(fs)^{TP},(fs,s)^{WMz}, (c,s)^{ME}	s^{TP}
Surface stoniness (%)	<3^{WMzTP} ,<10^{MKE}	3-15^{MzTP},10-15^{ME}, 10-30^{K}	15-40^{WMzTPM}, 30-50^{K}, 50-80^{E}	>40^{TPME}, 40-75^{WMz}, >50^{K}	>75^{WMz}
Relief	Normal^{all}	Flat^{all}	Concave^{all}	Concave^{all}	-
NPK rating	HHH^{all}	MMM^{ETPMK},MMH^{WMz}	MLL^{ETPMK},MMM^{Mz}	LLL^{ETPMK},LLM^{Mz}	LLL^{Mz}
pH	5.5-6.5^{T}, 5.8-6.5^{P},5.5-7.5^{M}	6.5-7.5^{T}, 6.5-7.0^{P},7.5-8.0^{M}	7.5-8.0^{T}, 7-7.5^{P},8-8.5^{M}	>8^{T}, >7.5^{P}, >8.5^{M}	-
Base saturation (%)	>70^{TPM}, >80^{WMzKE}	50-70^{TPM} ,50-80^{WMzKE}	35-50^{all}	<35^{all}	-

Crops : W-Wheat, Mz- Maize, T-Tomato, P-Pea, M-Mango, E-Eucalyptus, K-Khair; Rating : H-high, M-medium, L-low

Table 2. Physiography, land use and soil association in the watershed

Mapping Units	Dominant land use	Soil association	Area ha	Area %
Upper Shiwalik foot hills *(>600m, slope mostly >25 %)*				
H11	Higher altitude, mixed dense forests	Sandy-skeletal Lithic Udorthents / Sandy- skeletal Lithic Udipsamments	244	16.8
H12	Lower altitude, mixed dense forests	Sandy-skeletal Lithic Udipsamments / Sandy- skeletal Lithic Udorthents	311	21.4
H13	Sparse forests	Sandy-skeletal Lithic Udipsamments /Sandy- skeletal Lithic Udorthents /Sandy Typic Udorthents	18	1.2
Lower Shiwalik foot hills *(500-600m, slope mostly 10-35%)*				
H21	Mixed dense forests	Loamy-skeletal Typic Udifluvents	181	12.5
H22	Sparse forests	Sandy-skeletal Lithic Udipsamments	43	3.0
H23	Agriculture	Coarse-loamy Dystric Eutrudepts /Fine-loamy Typic Hapludalfs /Sandy Lithic Udipsamments	45	3.1
H24	Scrub land	Sandy Lithic Udipsamments /Loamy-skeletal Typic Udifluvents	91	6.3
H25	Grassland	Sandy Typic Udorthents /Sandy Lithic Udipsamments /Coarse-loamy Dystric Eutrudepts	42	2.9
Upper piedmonts *(450-500m, slope mostly 3-10%)*				
P11	Agriculture	Sandy Lithic Udipsamments /Fine-loamy Typic Hapludalfs /Coarse-loamy Lithic Udorthents	60	4.1
P12	Scrub land	Sandy Lithic Udipsamments /Coarse-loamy Dystric Eutrudepts	63	4.3
P13	Grassland	Sandy Lithic Udipsamments /Sandy Typic Udorthents /Coarse-loamy Dystric Eutrudepts	60.4	4.2
Lower piedmonts *(450-500m, slope mostly 1-10 %)*				
P21	Agriculture	Loamy Typic Hapludalfs /Sandy Lithic Udipsamments	57.9	4.0
P22	Agricultural plantations	Sandy Lithic Udipsamments	5.6	0.4
P23	Scrub land	Sandy Lithic Udipsamments /Sandy Typic Udorthents / Coarse-loamy Dystric Eutrudepts	71.8	5.0
P24	Grassland	Sandy Typic Udorthents /Coarse-loamy Dystric Eutrudepts /Sandy Lithic Udipsamments	52.3	3.6
Flood plains *(<450m, slope mostly 0-5 %)*				
FP1	Scrub land	Sandy Typic Udorthents /Sandy Lithic Udipsamments / Coarse-loamy Dystric Eutrudepts	29.4	2.0
FP2	Grassland	Coarse-loamy Dystric Eutrudepts /Sandy Lithic Udipsamments	16.0	1.1
FP3	Agriculture	Sandy Lithic Udipsamments /Fine-loamy Typic Hapludalfs /Sandy Typic Udorthents	6.9	0.5

Table 3. Salient characteristics of different mapping units

Mapping Unit	Slope class	Soil erosion	Soil depth (cm)	Soil texture	Surface stoniness (%)	pH (1:2)	OC ($g\ kg^{-1}$)	CEC [$cmol(p^+)kg^{-1}$]	BSP	NPK rating
H11	D-I	e2-e3	15-33	gsl - gls	30-45	6.74-6.98	10.5-10.8	6.8-12.5	74 - 76	MHL
H12	C-I	e2-e3	18-35	gsl - gls	35-50	6.57-6.82	11.0-12.0	7.8-14.4	76 - 79	MHL
H13	F-I	e2-e3	21-55	gsl - gls	30-50	6.43-6.65	10.8-15.9	6.9-12.4	72 - 75	LHL
H21	A-I	e1-e3	22-40	gsil - ls	>40	6.80-6.90	7.6-10.2	13.5-15.4	68 - 75	MHL
H22	F-H	e3	20-40	gls	>40	6.55-6.63	11.0-12.0	6.6-9.5	73 - 78	LHL
H23	A-G	e1-e3	9-105	l - gs	2-20	6.50-7.0	2.7-7.6	7.5-8.8	66 - 83	LHL
H24	A-G	e1-e3	7-35	gsil -gls	>35	6.76-6.86	3.0-7.6	10.3-13.5	66 - 73	LHL
H25	D-H	e1-e3	10-75	ls - gls	>40	6.58-6.78	4.8-14.0	6.0-7.9	65 - 76	LMM
P11	A-D	e1-e3	15-110	l - gls	2-15	6.79-7.10	4.5-6.8	4.7-11.3	74 - 84	LHL
P12	A-I	e1-e3	18-55	ls - gs	25	6.59-6.82	2.7-4.5	7.5-11.2	64 - 75	LHL
P13	A-G	e1-e3	21-52	ls - gs	40	6.25-6.78	4.8-13.9	5.8-10.6		LMM
P21	A-D	e1-e3	25-120	l - gls	2-13	6.75-6.98	4.6-6.6	8.7-11.3	73 - 84	LHL
P22	E	e2-e3	8-26	gls	25	6.76-6.89	3.9-4.4	9.2-11.4	72 - 74	LHL
P23	A-G	e1-e3	15-76	ls - gs	30	6.38-6.80	4.5-14.1	7.2-10.8	73 - 78	LHL
P24	A-G	e1-e3	9-74	ls - gs	36	6.35-6.78	5.0-13.9	7.7-10.5	74 - 77	LMM
FP1	B-D	e1-e3	19-56	gls- gs	32	6.52-6.76	4.8-5.0	7.2-10.1	73 - 76	LHL
FP2	A-D	e1-e3	23-60	ls - gs	38	6.55-6.81	2.7-4.9	5.7-9.5	62 - 79	LMM
FP3	A-C	e1-e3	24-100	l - gls	2-10	6.40-7.29	4.7-14.3	7.9-11.1	78 - 85	LHL

A=0-1%, B=1-3%, C=3-5%, D=5-10%, E=10-15%, F=15-25%, G=25-33%, H=33-50%, I=>50%; e1=slight, e2=moderate, e3=severe; g–gravelly, ls–loamy sand, sil=silt loam, sl= sandy loam, s= sand; L=low, M=medium, H=high

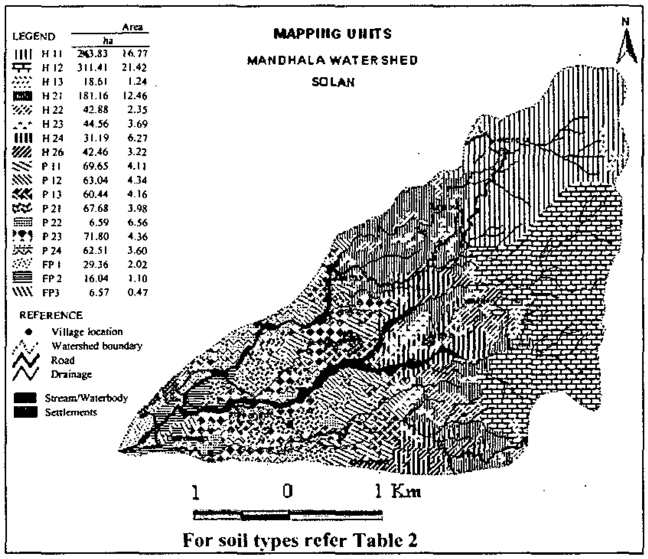

Figure 1.A

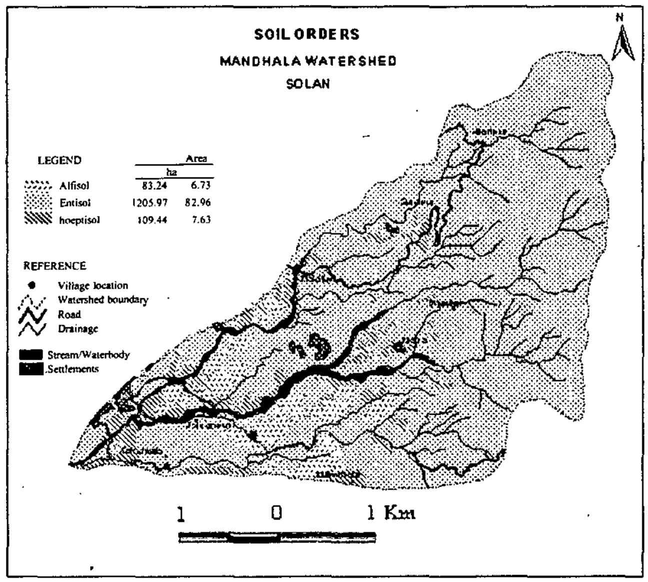

Figure 1.B

slightly acidic to neutral in reaction, very high organic carbon (OC) content, low to moderate CEC and moderate base saturation percentage (BSP).

Entisols and Inceptisols associated with Alfisols are the soils occurring on lower Shiwalik foot hills. This subunit represents extremely shallow to deep soils that are well drained, light to medium textured, slightly to severely eroded associated with neutral pH, moderate to very high OC content, low to moderate CEC and moderate to high BSP.

Piedmonts (P)

Several large fans descend from the Himalayan front

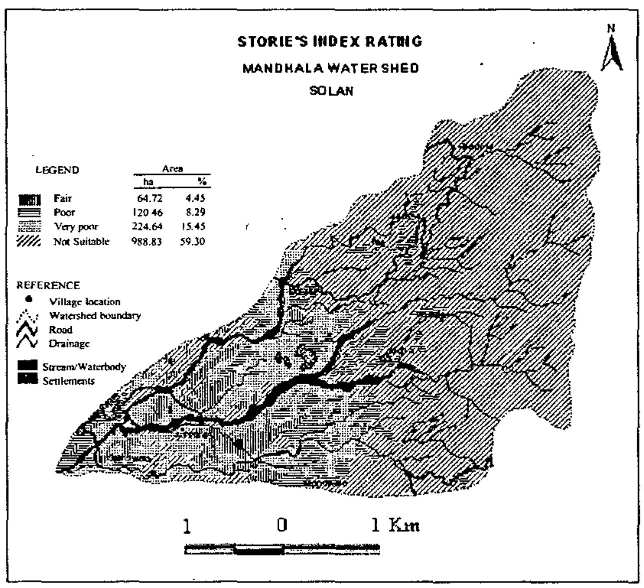

Figure 1.C

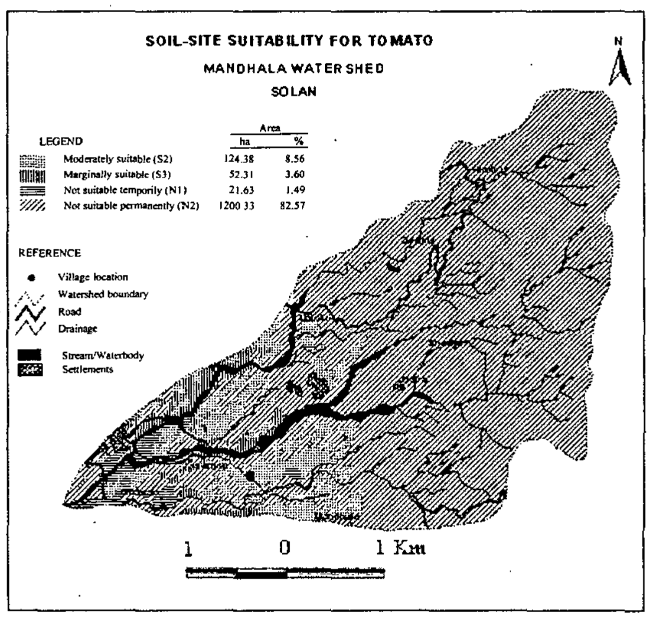

Figure 1.D

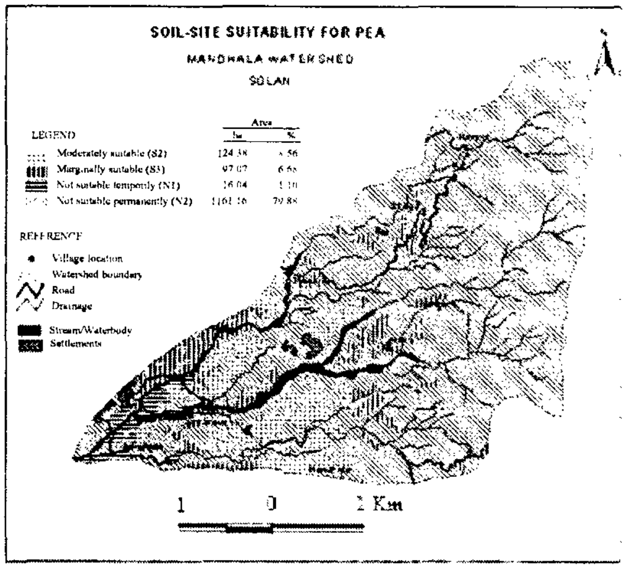

Figure 1.E

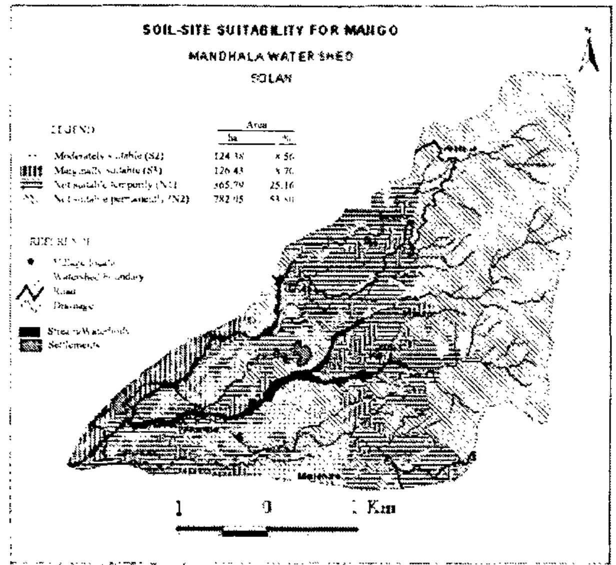

Figure 1.F

into the area. They coalesce to form the piedmonts. These were built by deposits from middle and lower Shiwaliks. This unit lies at an altitude of 450-500 m above msl and has 3-10% slope. It covers 370.69 ha (25.50%) area of the watershed. The piedmonts are divided into two sub-units *i.e.* upper piedmonts with slope 3-10% (P1) and lower piedmonts (P2) with slope (1-10%).

On the basis of land use, P1 is further sub-divided as P11 (agriculture), P12 (scrub land) and P13 (grassland) whereas P2 has sub-divisions as P21 (agriculture), P22 (agricultural plantations), P23 (scrub land) and P24 (grassland).

The dominant soils of upper piedmonts belong to Entisols associated with Alfisols and Inceptisols. These soils are very shallow to deep, well drained, light to medium textured, slight to severely eroded, slightly acidic to neutral,

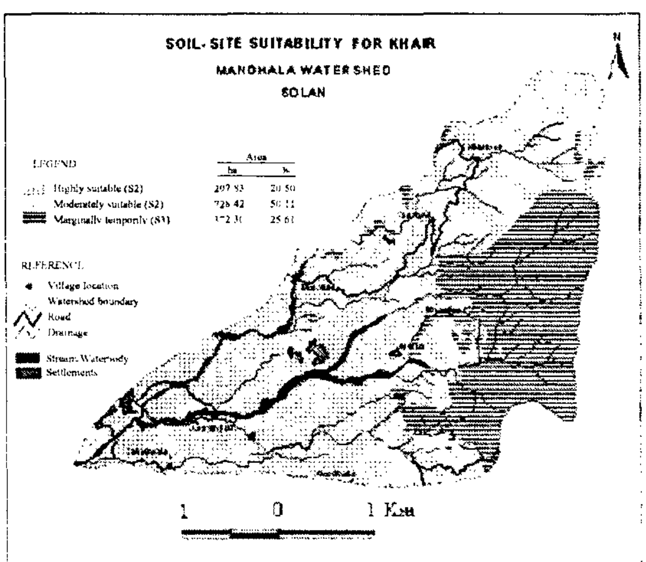

Figure 1.G

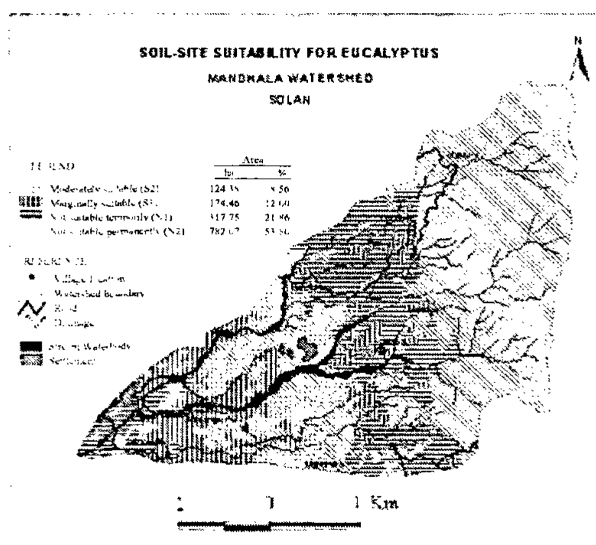

Figure 1.H

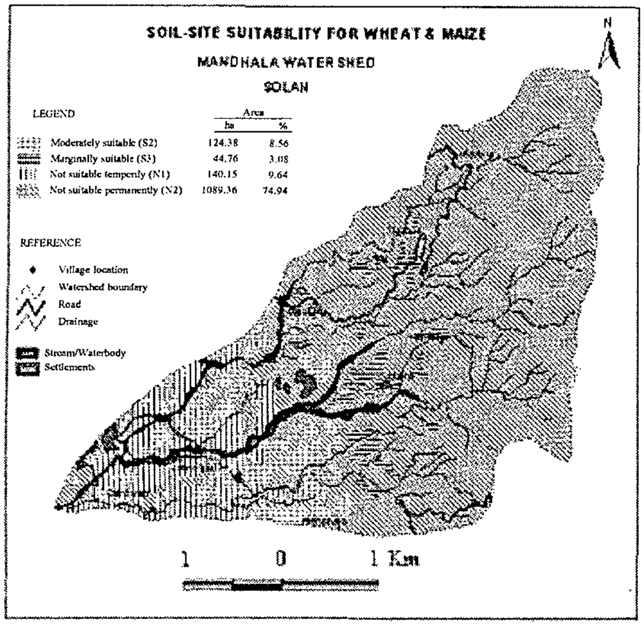

Figure 1-I

Fig. 1 (A-I). Soil resource and suitability map of Mandhala watershed

with moderate to very high OC content, low CEC and moderate to high BSP.

Entisols and Alfisols associated with Inceptisols are the soils in lower piedmonts. These soils are extremely shallow to deep, well drained, light to medium in texture, slightly to severely eroded, slightly acidic to neutral with moderate to very high OC content, low CEC and moderate to high BSP.

Flood plains (FP)

This unit represents river deposits and the area is affected by seasonal streams. It lies below 450 m above msl with slope less than 5 %. It covers relatively less area of the watershed (52.27 ha) *i. e.* 3.60 % of TGA. On the basis of land use, it is divided into three sub-units *i.e.* FP1 (scrub land), FP2 (grass land) and FP3 (agriculture). The soils of this unit belong to Entisols, Inceptisols and Alfisols. These soils are very shallow to moderately deep, well drained, light to medium textured, slightly to severely eroded, slightly acidic to neutral with moderate to very high OC content, low CEC and moderate to high BSP. The streams, water bodies, settlements and roads covered 54.88 ha of the watershed.

Productivity appraisal

The results pertaining to land productivity (Storie's Index) rating factors (A, B, C and X) are presented in table 4. It is observed that units having Entisols as dominant soils had lower values of A-factor (30-65) due to poor profile development (A-C profile), whereas units with slightly more developed soils (Inceptisols/Alfisols) have higher values of A- factor (65-80). Units P21 and FP3 (Alfisols and Entisols) had dominant fine- loamy soil textural class whereas H23 (Inceptisols and Alfisols) had coarse-loamy/fine-loamy textural class had higher values of B-factor *i.e.* 80. Other units had lower B-factor values (30-60) due to coarse texture. The C-factor values indicated that watershed had slope classes: <3% slope with C=100, <5% slope with C=95, 5-15% slope with C=90, 10-35% slope with C=80 and 25-50% slope with C=50. The computed X-factor values ranged from 42-72 due to variations in soil and land characteristics. On the basis of these four factors, the soils of the watershed have been placed in four categòries *i.e.* non agricultural (H11, H12, H13, H21, H22, H24, H25, P22 and P24 units), very poor (P12, P13, P23 and FP2 units), poor (H23, P11 and FP1 units) and fair (P21 and FP3 units). It is observed that units having Alfisols and Inceptisols as dominant or àssociated soils (P21, FP3, P11 and H23 units) had higher values of Storie's Index (42, 40, 23 and 22, respectively) as compared to Entisols where it ranged from 2-21. A close look at figure 1-C indicate that 4.45, 8.29 and 15.45% of TGA of the watershed fall in fair, poor and very poor land productivity classes, respectively, whereas, 59.30% of the area was found to be under non-agricultural class.

Soil-site suitability evaluation

Land suitability ratings in respect of different crops with various limitations at two levels of classification *i.e.* class and sub-class are given in table 5. The extent of various suitability classes has been spatially depicted in figure 1 (D to I)

Horticultural Crops

Tomato *(Lycopersicon esculentum)* is essentially a warm season crop. Generally elevation, controlling the temperature, determines the favourable environment for its growth making it possible to cultivate this crop in *kharif* season in mid hills of Himachal Pradesh. It prefers a moderate weather with annual rainfall of more than 1000 mm while the optimum temperature range is 18.5 to 26.5 °C for normal growth, development and setting of fruits. It is a deep rooted crop (having extensive root system mostly within 60 cm) which though requires plenty of water, cannot tolerate water-logging that results in poor growth, late flowering, fewer flower buds and lower fruit set besides increased disease incidence. The plant can grow well under a wide range of soil types *i.e.* from light sandy to fine textured heavy clays, provided they are deep, fertile, well drained and free from flood hazards. The light, warm soils are best suited for early production and high quality whereas loams and clay loams having higher water holding capacity are better suited for a longer production season when high yield rather than earliness is important. The crop is tolerant to acidity with optimum pH between 5.5 to 6.5. Below pH 5, liming may be required (Jones 1930). The suitable lity classes for tomato in given in figure 1 D.

Pea *(Pisum sativum)* is a cool weather high rainfall crop with optimum temperature range of 10-18 °C during growing period (extremes being 4 and 29 °C) that is frost free. With shallow rooted system and ability to fix atmospheric N, pea can grow well on a variety of soils ranging from light sandy loams (for early maturity) to heavy clays (for higher yields but late maturity). Well drained soils with high organic matter content allow better root aeration (Splittstoesser 1990) and thereby less root rot. Though crop prefers slightly acidic soils (optimum pH 5.8-6.5). High acidity is not tolerated and liming may be required below pH 5.5. The suit bility classes for pea in given in figure 1 E. Mango *(Mangifera indica)* is essentially a tropical fruit crop, and is grown in lower areas of Himachal Pradesh upto an altitude of 1400 m above msl. The crop can be grown upto a maximum temperature of 48 °C, optimum range being 24-30 °C. It can grow on all types of deep and well drained soils ranging from alluvial to lateritic ones (except black cotton soils) having pH upto 8.5 (optimum being 5.5-7.5). The plant is drought resistant and can withstand short periods of flooding. It is however, sensitive to saline conditions.

The data (Table 5) indicate that these lands differ greatly in their suitability towards different crops due to limitations of slope, depth, texture and fertility etc. About 8.56% area is moderately suitable for tomato and pea cultivation. The other categories for tomato included marginally suitable (3.6%), not suitable temporarily (1.49%) and not suitable permanently (82.57%), whereas those for pea comprised marginally suitable (6.68%), not suitable temporarily (1.10%) and not suitable permanently (79.88%). Nearly 8.56, 8.70, 25.16 and 53.80% of TGA was highly suitable, marginally suitable, not suitable temporarily and not suitable permanently respectively for mango (Fig. 1F).

Forestry/ agroforestry trees

Khair *(Acacia catechu)* is a tree of dry regions with a maximum temperature range of 32 to 39 °C. For optimum growth, annual rainfall of more than 500 mm is required. It thrives well on different types of terrain and soils *i.e.* porous sandy or gravelly alluvium and well drained loam or gravels with varying proportions of sand and clay. It can also grow on black cotton soils, shallow arid soils with kankar or even on fractured rock. On deep clays, drainage is crucial as impeded conditions result in stunted growth forcing the plant to die-off early (Troup 1921).

Safeda *(Eucalyptus teriticornis)* is hardy and has successfully adapted to a wide range of soils and climatic conditions.

A scrutiny of figure 1(G & H) shows that three categories of suitability were identified for khair *viz.* highly, moderately and marginally suitable covering 20.50, 50.11 and 25.61% of TGA respectively whereas, for safeda four categories of suitability identified as highly suitable, marginally suitable, not suitable temporarily and not suitable permanently and covered 8.56, 12.00, 21.86 and 53.80% of TGA, respectively.

Field Crops

Only 8.56% area was found to be highly suitable for wheat and maize, while large part of the area (74.94%) was found permanently not suitable for these field crops (Fig.1.I). Other categories for wheat and maize included marginally suitable (3.08%) and not suitable temporarily (9.64%).

Among the crops, SI ranged from 23.39 to 57.74, being highest for khair. This brings out that the area is comparatively more suitable for raising khair as indicated by SI value of 57.74 which is the highest among all crops studied.

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