Journal of the Indian Society of Soil Science, Vol. 69, No. 1, pp 1-13 (2021)
DOI: 10.5958/0974-0228.2021.00014.1

Soil Resource Inventory and Land Use Planning for Mandhala Watershed in Shiwalik Hills of North-West Himalayas using Remote Sensing and GIS

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Land resource mapping of Mandhala watershed representing Shiwalik hills of North-West Himalayas in Himachal Pradesh was done using multi-temporal and multi-spectral high resolution Indian remote sensing (IRS) satellite imagery and Survey of India (SOI) toposheets in conjunction with ground checks/field surveys to generate database layers including watershed boundary, drainage network, slope, landforms, land use/land cover, soils, land capability, suitability for major crops, suggested land use, *etc.* at 1:12,500 scale. About 55% of the watershed is under forests. Agriculture occupies about 12% area while rest is mainly under scrub and grasslands. These soils, still in initial stage of their pedogenic development, possess low productivity owing to inherent limitations related to topography, soil characteristics, erosion and erratic rainfall apart from excessive human interference. A need based resource conservation and land use plan consistent with the problems and potentialities identified in the area, was suggested by integrating different database layers in geographical information system (GIS) environment. The study also demonstrated utility of remote sensing (RS) and GIS techniques in sustainable natural resource development planning.

Key words: GIS, remote sensing, watershed, Shiwalik hills, land use planning

The Shiwalik hill ecosystem in North-West (NW) Himalayas owing to susceptible geology, steep topography, adverse climatic conditions and increased anthropogenic pressure on its natural resources resulting in declining land productivity, loss of biodiversity and rapid sedimentation of water bodies/ reservoirs, has been a matter of concern among researchers and planners since long. The very fact that famous Lake Sukhna of Chandigarh lost 65% of its storage capacity within just 10 years of its creation in 1958 mainly to the sediment load coming from Shiwalik catchment, only points towards gravity of the situation. During rainy season, heavy downpour in highly erodible Shiwalik hills results in flash floods/torrents which according to Central Water Commission 2000, contributes significantly to 3.9 million hectare (Mha) flood prone area of Himachal Pradesh constituting about 70% of total geographical area of the state. The valuable agricultural lands down under are swept away with the flood waters or rendered unproductive due to deposition of sand and gravels over them by inundating water. On an average, 50% of total rain in the Shiwaliks ends up in runoff (Mishra *et al.* 1978). The fragile land resource base which is eroding at an alarming rate of more than 80 tonne of soil loss ha^{-1} yr^{-1} in Shiwaliks (Sharma 2004) cannot sustain food and environmental security for long. There is an urgent need to bring the area under sustainable natural resource development plan following watershed approach, watershed being an appropriate unit for such planning especially in Himalayan region. This, however, demands a systematic inventory of land resources of watershed at an appropriate scale (1:12,500 or higher) which hitherto, is non-existent for the study area. The soil information of Himachal Pradesh available so far at 1:1 million (NBSS&LUP 2002), 1:1,25,000 (NBSS&LUP 2009) or even 1:50,000 scale is not effective for micro watershed level planning (Walia *et al.* 2010) due to scale limitation.

Application of modern technologies like remote sensing (RS) and geographical information system

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(GIS) in natural resource mapping and development planning is well recognized and its potential has been successfully utilized by many workers the world over (Sharma 2004). Present study, constituting a part of the co-ordinated programme 'Bio-Geo Database and Ecological Modeling of Himalayas' launched by Natural Resources Data Management System (NRDMS) division of Department of Science and Technology (DST), Govt. of India (GOI), was undertaken with the objective to create comprehensive land resource database, identifying problems and potentials and to suggest need based land use plan for a representative watershed using RS and GIS techniques.

Materials and Methods

Study Area

The study area, Mandhala watershed (30°53′45″ -30°56′15″ N latitude and 76°50′-76°54′ E longitude) comprising of 1453.53 ha area, constitutes a part of Kasauli development block in the southernmost part of district Solan in Himachal Pradesh (Fig. 1). It is situated about 18 km away from Pinjore along Pinjore-Nalagarh SH-15, Pinjore being on Kalka-Shimla NH-22. The watershed is also easily accessible by Kalka-Nalagarh/Kasauli-Barotiwala roads passing through it. Baddi and Barotiwala are two highly industrialized towns situated in the vicinity of the watershed. There are eight revenue villages namely Mandhala, Sainsiwala, Kulhariwala, Johranpur, Bhagnuwala, Haripur, Majri and Dhaular covering the watershed. The entire watershed is a rural area with scattered villages, each having 15-30 households.

Climate of the area is sub-humid sub-tropical characterized by extreme summers and severe winters. Mean winter and summer months temperatures are 18 and 25 °C, respectively and highest is observed in the month of June. Average annual rainfall is about 1000 mm, most of which is concentrated during monsoon season (mid June-mid September). Monsoon rains in the area are heavy and intense. However, very little rain is received during winter months leading to frequent crop failures due to long dry spells. The area has 'Udic' moisture and 'Hyperthermic' temperature regimes. It falls in zone-1 (sub-tropical sub-montane and low hills) of the agro-climatic zones of Himachal Pradesh.

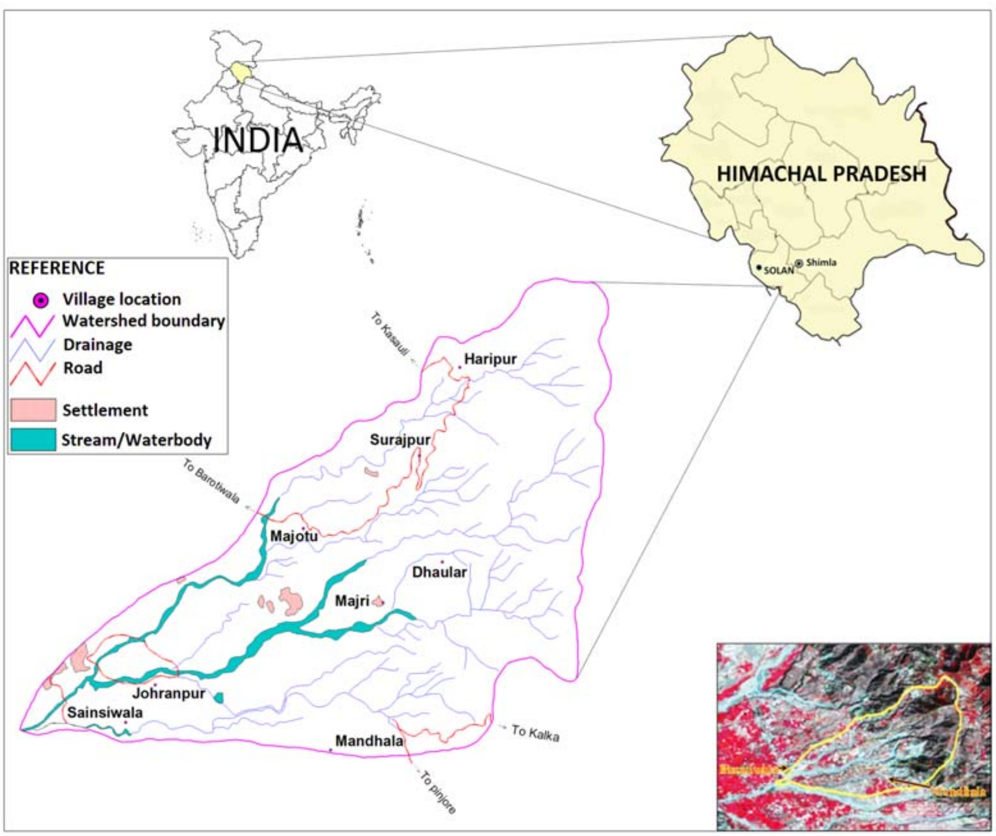


Fig. 1. Location/Base map of Mandhala watershed showing drainage, road network, prominent village locations, settlements *etc.* with satellite image in inset covering study area

Water resources

There is no major perennial stream flowing through the watershed and massive sandstone rock units are the only source of ground water in the region. Two seasonal streams and few rivulets are the major sources of irrigation water during monsoon months only. Some old farm ponds and wells, earlier used for irrigation and drinking water purpose, have been rendered useless because these have either dried up or abandoned in wake of various irrigation schemes, hand pumps and tube wells installed by government agencies. A few people have their own private tube well connections also. The area has good facilities for potable water.

Data used

Survey of India (SOI) maps at 1: 50,000 scale with 10 m contour interval, IRS-1C LISS III + PAN merged data (5.8 m resolution) of November 10, 2001 were geo-referenced using preferably Everest Datum, Polyconic map projection and Ground Control Points (GCPs). Scale of the study was 1:12,500. Mapping (planimetric) accuracy achieved was 3.75 m *w.r.t.* control points and classification accuracy was 90% according to sample check in the field. A digital elevation model (DEM) of the study area with 6 m pixel resolution was derived from contours of SOI maps at 1:50,000 scale and contour interval of 10 m.

Methods

Three tier approach *viz.*, image interpretation, field surveys and laboratory analysis followed by cartography and GIS was adopted. Watershed boundary was delineated from the published SOI maps at 1: 50,000 scale by drawing lines perpendicular to the elevation contour lines for land draining to common outlet (Proff *et al*. 2005). Also, the information on drainage, road network, settlements, village locations, water bodies and slope was extracted from SOI maps. These maps were enlarged up to 1:12,500 scale and overlaid with visually interpreted high resolution geo coded LISS III + PAN merged data of IRS-1C satellite pertaining to November 10, 2001 (Fig. 2) to extract study area, information on drainage, landforms, land use/land cover, *etc*. LISS III sensor of IRS-1C satellite used in the present study, has four spectral bands in green (0.52-0.59 µm), red (0.62-0.68 µm), NIR (0.77-0.86 µm) and SWIR (1.55-1.70 µm) wavelength regions. It has 23.5 m spatial resolution in first three bands (VNIR) and 70.5 m spatial resolution in SWIR band. The PAN imagery of IRS-1C has 5.6 m spatial resolution. Thus, limited

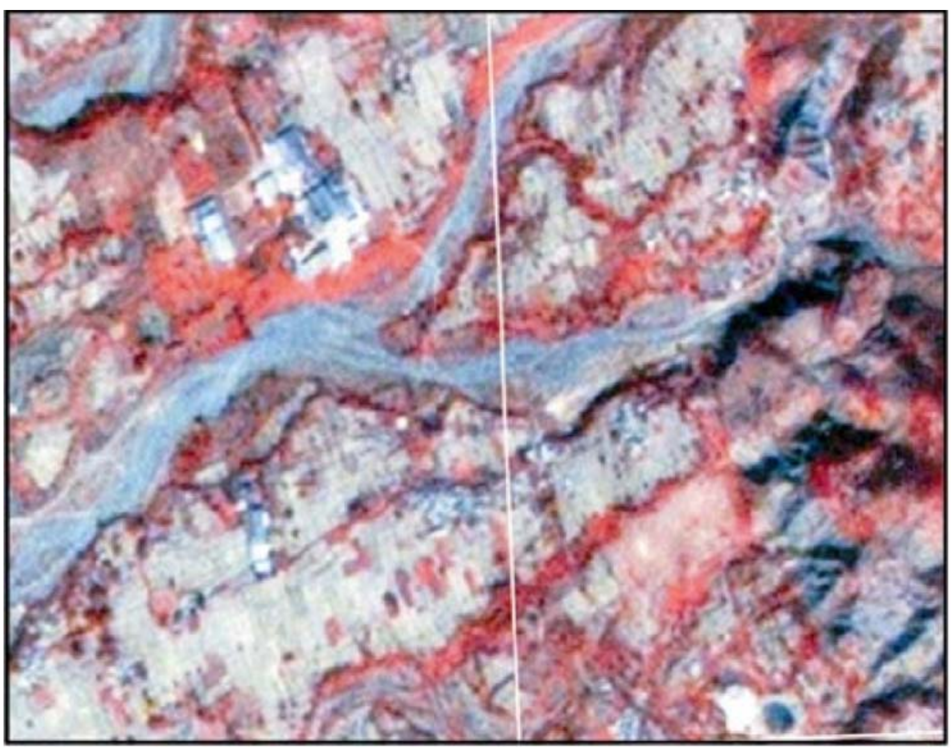


Fig. 2. IRS-1C PAN + LISS III satellite image of a part of Mandhala watershed

information derived from SOI maps was updated using high resolution satellite data. This process facilitated identification of major and minor details, enabling all the 1st order drainages and their drain orders with individual hydrological entities to be taken into consideration.

After the pre-field visual interpretation was over, output was generated for actual ground verification. All sample points during pre-field interpretations were verified using global positioning system (GPS) and correctly incorporated in the final map. Efforts were made to check all features according to the existing satellite images to enhance map interpretation accuracy.

Layers containing information on landform, land use, slope, elevation, erosion, drainage/road network, settlements and prominent village locations were superimposed and used as base for conducting detailed soil survey of the watershed. In all, thirty two pedons were studied up to a depth of 1-1.5 m or lithic/paralithic contact and horizon wise soil samples taken from representative pedons for physicochemical characterization following standard laboratory methods (Jackson 1973; Sarma *et al.* 1987). In order to supplement profile investigations, additional auger bores, mini-pits and road cut observations were taken at regular intervals of 50-200 m across landforms depending upon heterogeneity of terrain (Walia *et al.* 2010). Surface features like slope, existing land use, erosion status and other morphological characters were also recorded in the field. During survey work, field reviews were conducted to correlate and classify the soils up to phases of soil series (Soil Survey Staff 2000). Soil mineralogy was considered to be 'mixed'. Properties having significant bearing on management *i.e.* slope, soil depth, surface texture, gravelliness/stoniness and erosion status were used as differentiating characteristics to identify soil phases. Since all soils were well drained, so drainage was omitted from phase description. Accordingly, soil boundaries were refined, delineated, checked and confirmed by actual traversing (AIS&LUS 1971; Sehgal *et al.* 1987). A broad grouping of soils for different land use options was done on the basis of land capability classification of USDA (Klingabiel and Montgomery 1961) as modified for NW Himalayas (Hudson 1979; Khybri 1979; Singh and Minhas 1988; Singh *et al.* 1991). However, for assessing specific soil-site suitability for various agricultural, horticultural and forestry crops of economic importance grown in the area, modified approach of Sehgal (1986) and Sys *et al.* (1991, 1993) based on the FAO frame work of land suitability evaluation (FAO 1976, 1993) was adopted.

Using the final updated and corrected maps at 1:12,500 scale after the process of map scanning, digitization, editing, vectorization, polygonization, geo-referencing and map projection; various thematic maps *viz.*, landforms, land use/land cover, soils, land capability, suitability for major crops, *etc.* were created. The database was processed and integrated in GIS environment using Arc/Info Workstation software (version 7.4) of ESRI, Redland, California (USA) and a land use plan for sustainable development of watershed resources was suggested. Derived maps including slope, aspect, hydro geomorphology *etc.* generated during the study and not presented here, can be accessed from the official web portal of DST, GOI.

Results and Discussion

Landforms, relief and drainage

Physiographically, the watershed represents lower Shiwalik hills of Himalayan region covered by SOI toposheet No. 53 F/13. Based on visual interpretation of satellite data for image elements like tone, texture and pattern along with topographical variations like altitude as depicted by DEM (Fig. 3), slope and aspect followed by ground checks; five major landforms were delineated (Fig. 4). A substantial, about 67% portion of the watershed is under steep hill slopes (upper and lower). This portion of the watershed is highly rugged and dotted by frequent elevations and depressions. Piedmonts (upper and lower) cover about 25% area of the watershed. A relatively smaller portion of the watershed (about 4%) represented by river deposits and the area affected by seasonal streams constitutes flood plains. Use of precision PAN+LISS III merged data made it possible

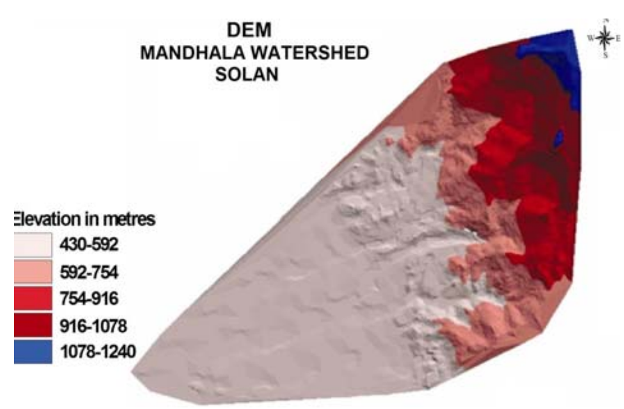


Fig. 3. Digital elevation model (DEM) of Mandhala watershed

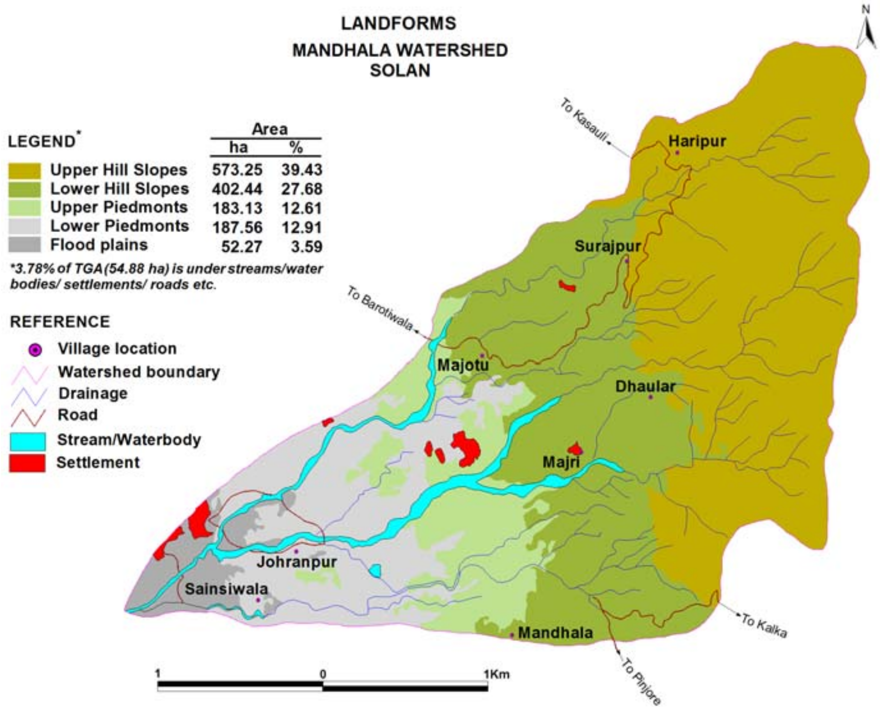


Fig. 4. Landforms in Mandhala watershed

to map drainages of all orders including 1st and 2nd orders as on ground. The watershed has fine textured dendritic drainage pattern of high density. It is drained by River Sirsa falling in nearby Haryana state through two seasonal streams (locally known as '*choes' or 'raos*') and a few rivulets ultimately merging with River Sutlej.

Land use/ land cover

Six major land use/ land cover classes *viz.*, mixed dense forest, sparse forest, scrub land, grassland, agriculture and agricultural plantations have been identified in the watershed (Fig. 5). About 55% of the watershed is under forest comprising *Acacia catechu, Acacia nilotica, Cassia fistula, Dalbergia sissoo, Azardirachta indica, Butea monosperma* and *Anogeissus latifolia* as main tree species with associated shrubs like *Adhatoda vesica, Carrisa spinarum, Dodonaea viscosa, Ipomea carnea, Vitex negundo, Lantana camara*, *etc.* These shrubs also dominate scrub lands occurring in about 18% of area. Grasslands and agriculture, each occupies about 12% area. Of the total agricultural land, the cultivated area is about 51%, out of which only about 18% is irrigated. Major cropping seasons are *kharif* and *rabi*. Area under *kharif* is about 43%. Maize (*Zea mays*) is the main *kharif* crop grown along with rice (*Oryza sativa*) in certain low land areas having sufficient water. About 38% area is under *rabi* with wheat (*Triticum aestivum*) as main crop. Important vegetable crops grown in the area are pea (*Pisum sativum*), tomato (*Lycopersicon esculentum*), potato (*Solanum tuberosum*), cabbage (*Brassica capitata*), cauliflower (*Brassica oleracea*) and mustard (*Brassica juncea*). Some farmers also cultivate sugarcane (*Saccharum officinarum*), groundnut (*Arachis hypogea*) and gram (*Cicer arietinum*) in small pockets. A small portion (approximately 0.4%) is under mango (*Mangifera indica*) plantations while nearly 4% of the watershed is occupied by rivers/waterbodies/roads and settlements *etc.*

Geology and soils

The soils of hilly terrain of the watershed are formed on soft sandstones, poorly sorted/bedded conglomerates, brownish clays and boulder beds. Shallow to deep, light textured soils occurring on upper hill slopes are classified as Lithic/Typic Udorthents, Lithic Udifluvents while light to medium textured soils occupying lower hill slopes are classified as Lithic Udifluvents, Typic Udorthents/ Udipsamments/Hapludalfs sub group associations. Piedmonts and flood plain soils are developed on alluvium derived from hills and carried by seasonal

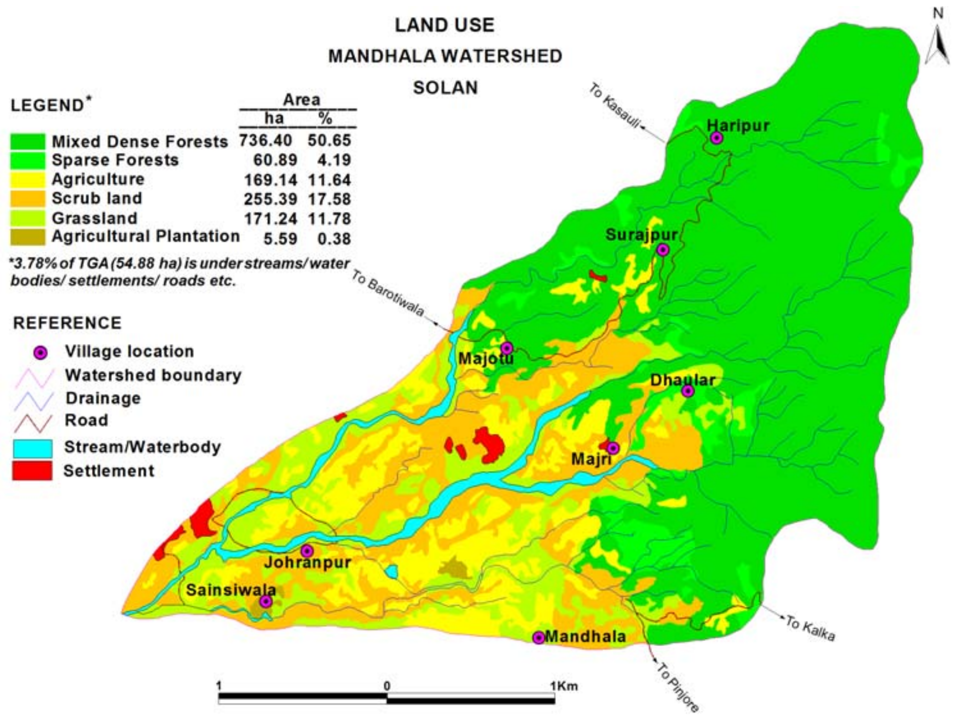


Fig. 5. Land use distribution in Mandhala watershed

streams. Shallow to very deep soils occurring in piedmonts are classified as Lithic/ Typic Udipsamments, Typic Udorthents/Hapludalfs and Lithic Udifluvents while those in flood plains, light to medium in texture; are classified as Lithic Udifluvents, Typic Udorthents/ Udipsamments/ Hapludalfs sub group associations. The studied soils were young, majority being in initial stage of pedogenic development with A-C profile sequence dominated by order Entisols covering about 91% of the watershed while Alfisols covered about 6% of the watershed area. The soils are rich in organic carbon (OC) especially in surface layers and characterized by slightly acidic to neutral pH, low to moderate cation exchange capacity (CEC) and moderate to high base saturation percentage (BSP) (Table 1). The soils were mapped into 28 phases (Fig. 6) of eight series.

Causes of land degradation identified in the area

The watershed is situated at the border of two states *i.e.* Punjab and Haryana near thickly populated Union Territory of Chandigarh besides its close proximity to Baddi and Barotiwala, the two highly industrialized and rapidly expanding towns of Himachal Pradesh. The demand for building materials such as sand, gravel and boulders for developmental activities in these areas is met to a large extent from the watershed and adjoining areas. The quarrying/ mining activities being carried out within the watershed are posing serious threat to its ecology. Chandigarh Shiwaliks suffer from high rate of soil loss averaging 367.5 t ha^{-1} yr^{-1} consequential to developmental boom experienced by Chandigarh (Singh 1996). As a result of high runoff rates, considerable area of the watershed has turned into deep *choes* draining into River Sirsa. Indiscriminate exploitation of forests for fuel wood, timber, fodder/ grazing by local people including many migrant labourer families residing in the watershed area while working in nearby industrial units is putting excessive pressure on already fragile natural resources, thereby hindering greatly the regeneration of forests in the region. Sharma (2004) ascribed denudation of Shiwalik hills largely to the extraction of fuel wood by the local people in excess of yields. Majority of the farmers are poor having small, fragmented land holdings and are unable to invest much on expensive inputs of modern farming. As such, they continue to follow traditional cultivation practices that are inherently less environmental friendly apart from being less remunerative.

Land capability and suitability classification

The study area has been grouped into six land capability classes through analyses based on capability, expected response to management and

Table 1. Physicochemical characteristics of the soils

Horizon	Depth (cm)	Particle size distribution (%)			Texture	pH (1:2)	Org C (g kg^{-1})	CEC [cmol(p^+)kg^{-1}]	BSP (%)
		Sand (0.02-2.0 mm)	Silt (0.002-0.02 mm)	Clay (<0.002 mm)					
Johranpur series* - Fine loamy, mixed, hyperthermic, Typic Hapludalfs									
Ap	0-15	66	26	8	ls	6.95	6.6	7.8	82.8
Bt1	15-40	52	26	22	sil	7.29	5.1	12.1	84.5
Bt2	40-70	48	32	20	sil	7.20	3.9	13.9	80.8
C	70-100	69	13	18	l	7.10	3.9	13.5	78.4
Mandhala I series - Coarse loamy, mixed, hyperthermic, Typic Udipsamments									
Ap	0-8	90	2	8	gs	6.25	2.7	7.5	61.7
AC	8-40	80	10	10	ls	6.82	1.5	10.2	66.5
C	40-60	78	11	11	ls	6.64	1.8	11.2	66.7
Mandhala II series - Coarse loamy, mixed, hyperthermic, Lithic Udipsamments									
Ap	0-10	84	2	14	sl	6.80	3.9	5.2	73.6
AC	10-23	82	4	14	sl	6.90	2.1	4.7	82.0
R	23+	Hard substratum							
Mandhala III series - Sandy, mixed, hyperthermic, Typic Udorthents									
A	0-20	82	12	6	gls	6.38	15.9	5.8	71.6
AC	20-75	74	18	8	gls	6.59	13.9	7.8	77.7
R	75+	Hard substratum							
Mandhala IV series - Coarse loamy skeletal, mixed, hyperthermic, Lithic Udifluvents									
A	0-10	58	38	4	gsil	6.80	10.2	15.4	68.2
2C	10-22	66	32	2	gsil	6.90	4.2	13.5	75.4
R	22+	Hard substratum							
Majri series - Sandy, mixed, hyperthermic, Lithic Udifluvents									
A	0-15	64	26	10	gls	6.76	4.5	11.4	71.5
R	15+	Hard substratum							
Dhaular series - Sandy skeletal, mixed, hyperthermic, Lithic Udifluvents									
A	0-17	72	20	8	gls	6.55	12.0	6.6	75.7
Cr	17-40	Semi weathered sandstone							
Haripur series - Sandy skeletal, mixed, hyperthermic, Lithic Udorthents									
A	0-10	78	16	6	gls	6.74	10.5	12.5	80.1
AC	10-21	80	8	12	gsl	6.98	7.5	14	81.2
R	21+	Hard substratum							

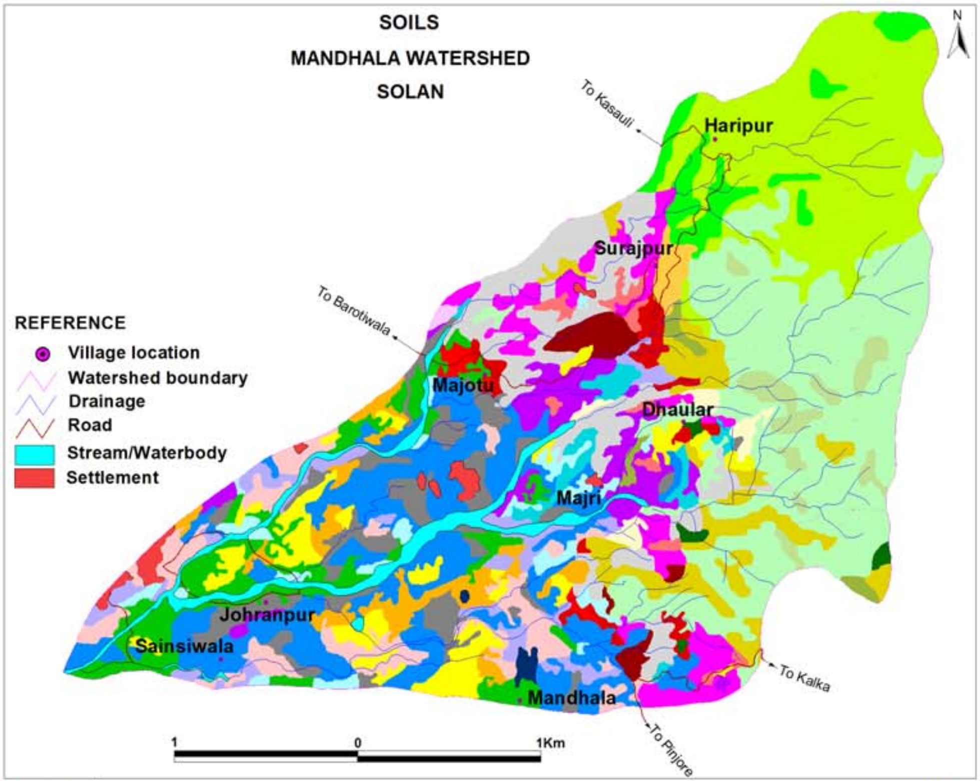
*Thin, patchy clay argillans (indicative of clay illuviation) were observed in B horizon (Sharma and Chaudhary 2006)

limitations to agriculture (Fig. 7) : class II (good cultivable lands), class III (moderately good cultivable lands), class IV (fairly good cultivable lands), class V (non-arable lands suitable for grazing), class VI (non-arable lands suitable for grazing or forestry) and class VII (lands fairly well suitable for grazing and forestry) comprising 4.83, 4.11, 3.08, 29.35, 15.41 and 39.44% of total geographical area of the watershed in respective classes (Fig. 8). Major part of the watershed covering about 84% area was found unfit for cultivation, only 12% being suitable for arable farming. About 9% of the watershed area was found suitable/moderately suitable for crops like wheat, maize, pea, tomato, mango and eucalyptus whereas about 14 and 71% area falling in these categories suited to mustard and khair, respectively (Figs. 9 and 10). Land occurring in hill slopes and upper piedmonts had major limitations of steep slopes, soil (low fertility, shallow depth and/or coarse texture with/without gravelliness/ stoniness) and susceptibility to erosion. Lower piedmonts had soil related limitations whereas flood plains had major limitations related to soil, erosion and flood hazards.

Resource conservation and land use plan

Fig. 11 shows the methodology and fig. 12 depicts a broader overview of the suggested land use.

Class II lands are suitable for cereal crops like wheat and maize, pulses like gram, oil seeds like mustard, cash crops like sugarcane and potato, vegetables like pea and tomato *etc.* as well as for horti-agricultural land use following proper crop rotation, balanced fertilization and addition of manures. Further, improvement of existing terraces to graded bunds /broad based terraces can greatly reduce erosion hazards and improve the productivity of flood



LEGEND*	AREA ha	AREA %
Johranpur series - Fine loamy, mixed, hyperthermic, Typic Hapludalfs		
Nearly level to very gently sloping, deep to very deep, slightly eroded	46.41	3.19
Gently to moderately sloping, deep to very deep, slightly eroded	36.83	2.54
Mandhala I series - Coarse loamy, mixed, hyperthermic, Typic Udipsamments		
Nearly level to gently sloping, moderately deep to deep, gravelly, moderately to severely eroded	69.00	4.75
Moderately to strongly sloping, deep, gravelly, moderately to severely eroded	27.22	1.87
Moderately steep to steep, deep, gravelly, moderately eroded	13.22	0.91
Mandhala II series - Coarse loamy, mixed, hyperthermic, Lithic Udipsamments		
Nearly level to gently sloping, moderately deep, sandy, slightly eroded	3.46	0.24
Mandhala III series - Sandy, mixed, hyperthermic, Typic Udorthents		
Nearly level to gently sloping, moderately deep to deep, gravelly, slightly to severely eroded	63.63	4.37
Moderately to strongly sloping, moderately deep to deep, gravelly, slightly to severely eroded	35.42	2.44
Moderately steep to steep, moderately deep to deep, gravelly, slightly eroded	9.16	0.63
Steep to very steep, moderately deep to deep, gravelly, slightly eroded	11.00	0.76
Mandhala IV series - Coarse loamy skeletal, mixed, hyperthermic, Lithic Udifluvents		
Nearly level to gently sloping, shallow to moderately deep, gravelly, slightly eroded	6.08	0.42
Moderately sloping, shallow to moderately deep, gravelly, slightly eroded	18.67	1.28
Strongly sloping, shallow to moderately deep, gravelly, slightly eroded	18.00	1.24
Moderately steep to steep, shallow to moderately deep, gravelly, moderately eroded	95.24	6.55
Steep to very very steep, shallow to moderately deep, gravelly, moderately eroded	49.41	3.40
Majri series - Sandy, mixed, hyperthermic, Lithic Udifluvents		
Nearly level to very gently sloping, shallow, gravelly, slightly eroded	65.55	4.51
Gently to moderately sloping, shallow, gravelly, slightly to severely eroded	167.44	11.52
Strongly sloping, shallow, gravelly, moderately to severely eroded	18.75	1.29
Moderately steep to steep, shallow, gravelly, moderately to severely eroded	39.82	2.74
Very steep to very very steep, shallow, gravelly, moderately eroded	1.59	0.11
Dhaular series - Sandy skeletal, mixed, hyperthermic, Lithic Udifluvents		
Gently to moderately sloping, shallow, stony, moderately eroded	4.64	0.33
Strongly sloping, shallow, stony, severely eroded	7.95	0.55
Moderately steep to steep, shallow, stony, severely eroded	61.85	4.24
Steep to very steep, shallow, stony, severely eroded	260.23	17.90
Very very steep, shallow, stony, severely eroded	26.44	1.82
Haripur series - Sandy skeletal, mixed, hyperthermic, Lithic Udorthents		
Moderately sloping, shallow, stony, moderately eroded	9.62	0.66
Moderately steep to steep, shallow, stony, modertely eroded	33.12	2.28
Steep to very very steep, shallow, stony, moderately eroded	198.90	13.68

**3.78% of TGA (54.88 ha) is under streams/water bodies/settlements/roads etc.*

Fig. 6. Soil map of Mandhala watershed

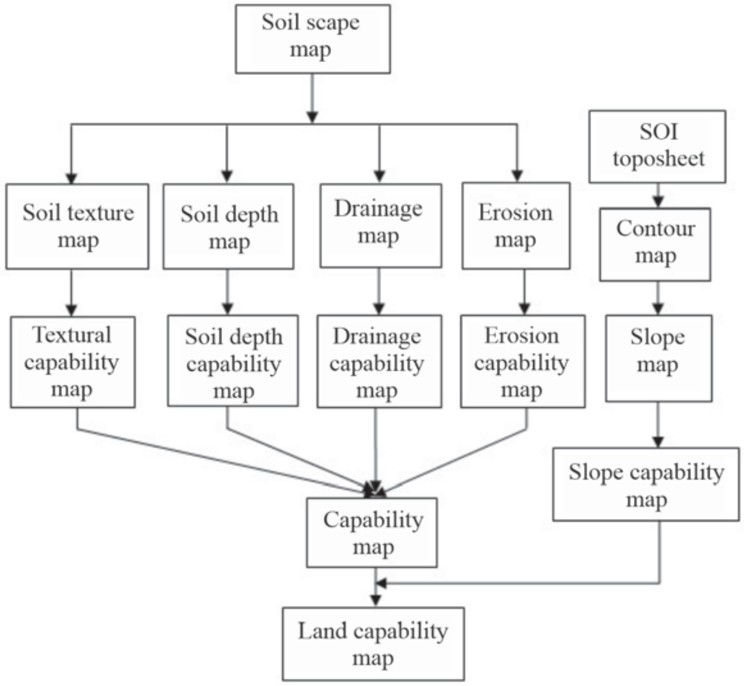


Fig. 7. Methodology for land capability classification using GIS

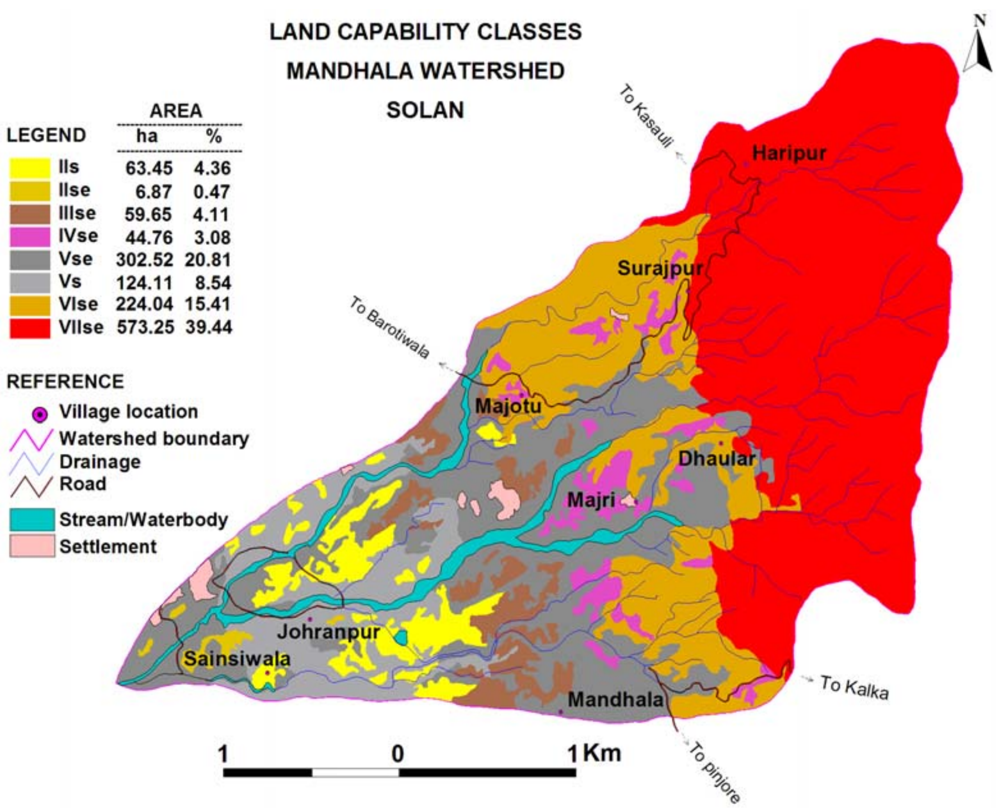


Fig. 8. Land capability of Mandhala watershed

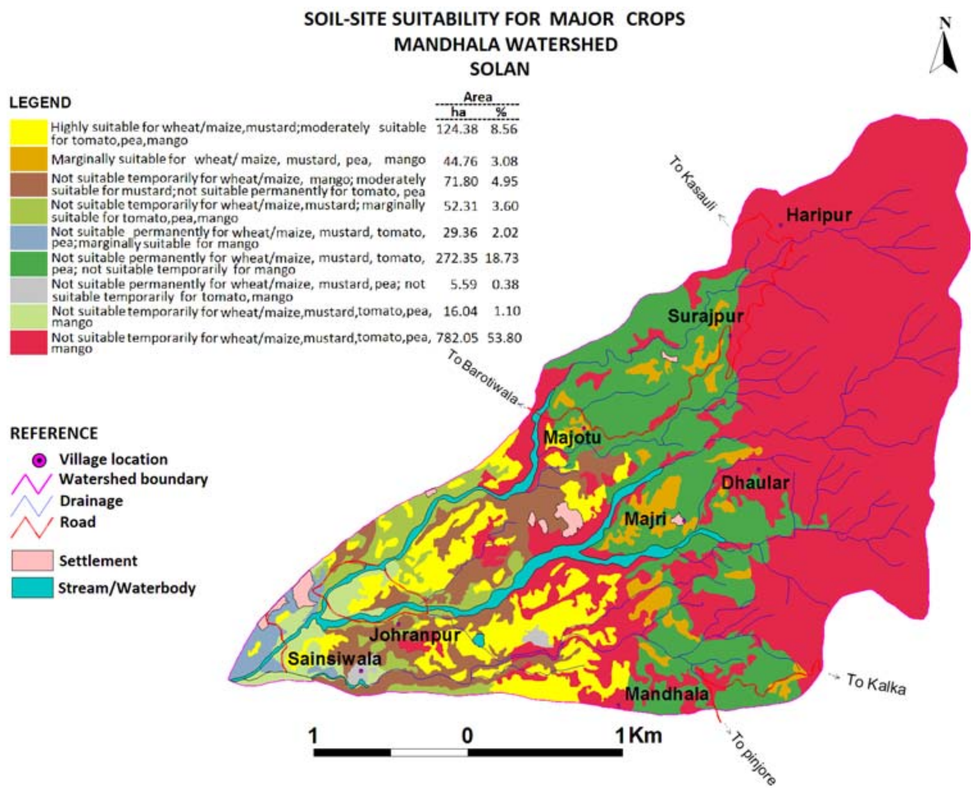


Fig. 9. Soil-site suitability for major agricultural and horticultural crops of Mandhala watershed

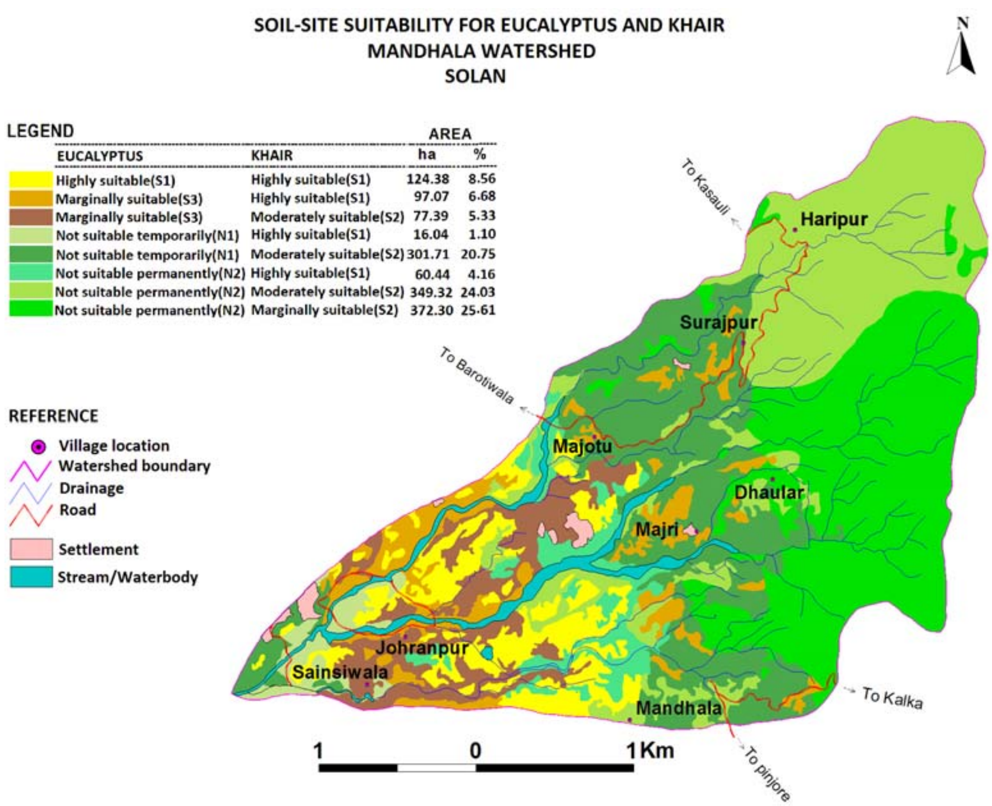


Fig. 10. Soil-site suitability for multipurpose trees of Mandhala watershed

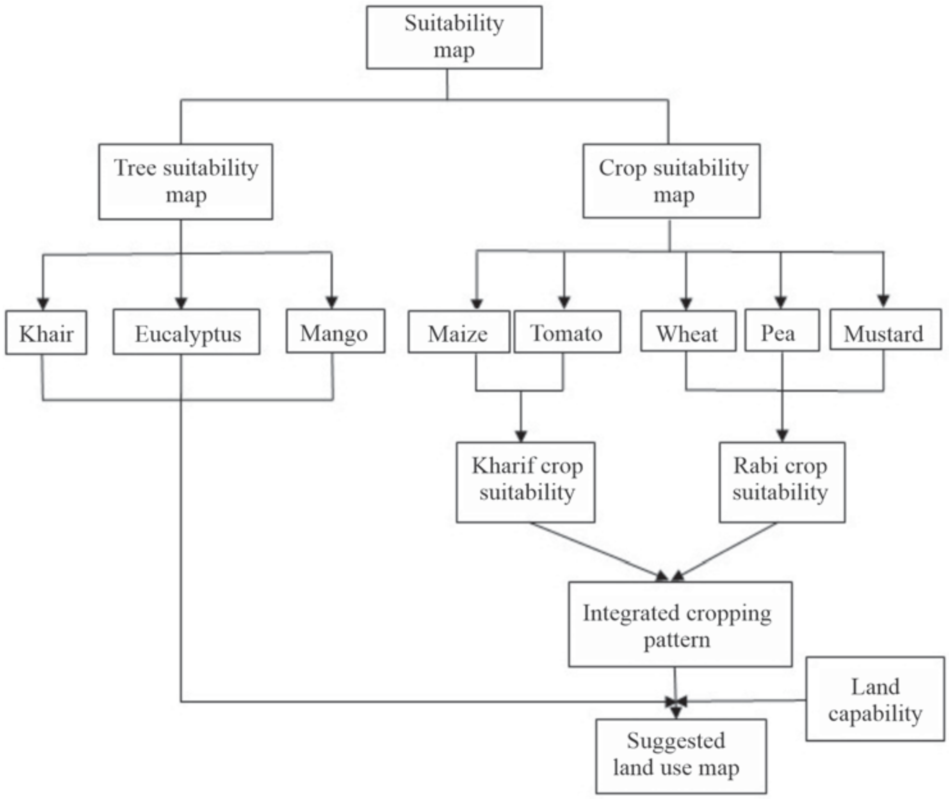


Fig. 11. Methodology for suggesting land use using GIS

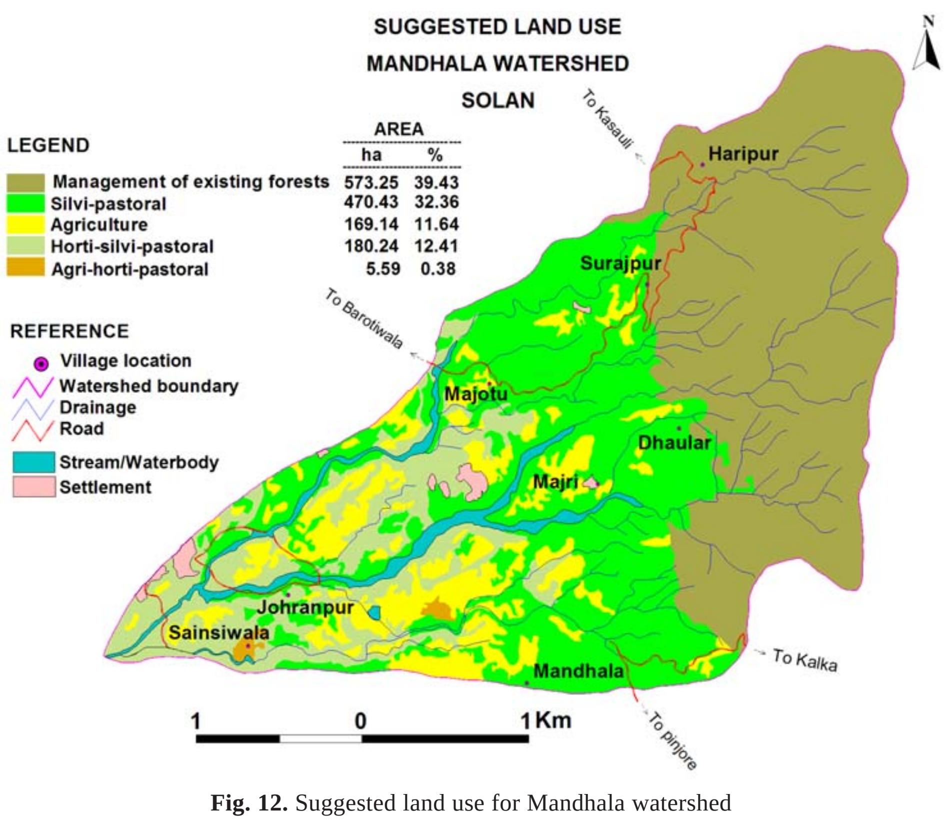


Fig. 12. Suggested land use for Mandhala watershed

plains under this category. Lower terraces with slight flood hazards during rainy season should be put to rice cultivation. Class III lands moderately good for agriculture, have to be cultivated with precaution adopting recommended package of practices with graded trenches or broad based/bench terraces. Class IV lands have same limitations as those in class III lands but with greater degree and should be put under agriculture with bench terraces, drop pits and drains along with sufficient cover cropping/mulching wherever needed (Singh and Bhandari 2000). Proper land leveling should be ensured in areas where irrigation is possible. The field bunds can be planted with fruit trees /multipurpose tree species. Class V and VI lands could be used for grazing or pasture development with combinations of horticulture and forestry species depending on the limitations of slope, soil and erosion. The forestry species suitable for these lands are *Acacia catechu*, *Acacia nilotica*, *Butea monosperma*, *Eucalyptus teriticornis*, *Populus* species, *Albizzia lebbek*, *Leucaena leucocephala*, *Morus alba* and *Dendrocalamus strictus*, *etc*. while preferred horticultural tree crops are *Magifera indica*, *Citrus* species, *Litchi chinensis*, *Psidium guajava*, *Phylanthus emblica*, *Zizyphus jujube*, *etc*. Among grasses are *Eulaliopsis binata*, *Saccharum munja*, *Saccharum spontaneum* and *Pennisetum purpureum*. Fodder crops like *Trifolium alexandrinum*, *Trifolium resupnatum* and *Medicago sativa* can also be grown in flood plains. *Dalbergia sissoo* and *Ipomea carnea* planted along '*choe*' banks/gullies as vegetative barriers can prove highly effective for erosion control (Katiyar *et al.* 2007). Class VII lands, good for forestry only, should be kept under perennial tree cover and further enriched in order to meet the fuel wood, timber, fodder demand of local people. Class VI and VII lands should be protected with low cost bio-engineering soil and water conservation measures such as stone wall, contour trenches, mulch, cover crops *etc*. Mining/ quarrying and grazing should be strictly avoided to ensure the effectiveness of adopted conservation measures. Also, in order to reduce dependency on rains, local people need to be motivated to adopt efficient soil and water conservation measures like rooftop rain water harvesting, low cost LDPE lined farm ponds and micro-irrigation by providing trainings/incentives. Verma *et al*. (2000) also suggested similar conservation measures for Shiwaliks.

Conclusions

Detailed inventory of watershed resources provided insight into the problems and potentials of the area. These lands suffer from different constraints limiting their use to varying degrees and hence need prompt conservation measures. Resource degradation has been exaggerated by excessive human intervention and indiscriminate use. The study provided clues for selection/improvement of appropriate land use in order to realize full potential of these lands. Remote sensing and GIS greatly facilitated land use planning of this otherwise difficultly accessible hilly terrain. The digital database will be helpful to natural resource managers, policy planners and decision makers besides farming community by providing reliable information on watershed resources. The suggested resource conservation and land use plan may be replicated elsewhere under similar agro-ecological conditions.

Acknowledgements

We thank Brig. (Dr.) Shiva Kumar, Head (NRDMS&NSDI) and Mrs. Nisha Mendiratta, Additional Director (NRDMS Division), DST, New Delhi for financial support. We are grateful to Dr. R.K. Sood, Joint Member Secretary and Mr. R.S. Thapa, Sr. Scientific Officer (HP State Council for Science, Technology and Environment, Shimla) for providing GIS facilities and digital data.

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Received 21 September 2019; Accepted 12 March 2021