Use of high-resolution IKONOS data and GIS technique for transformation of landuse/ landcover for sustainable development

P. Kunwar[1,*], T. S. Kachhwaha[1], Anil Kumar[1], A. K. Agrawal[1], A. N. Singh[1] and Nisha Mendiratta[2]

[1]Remote Sensing Applications Centre, Lucknow 226 007, India
[2]Department of Science and Technology, New Delhi 110 016, India

Sustainable development has assumed utmost importance in view of the increasing demands on the finite natural resources due to increasing population and need to protect fragile environment. Remote sensing and GIS techniques have capability to assess the available natural resources and its use, and provide information for transformation of alternative landuse, if the resource is not optimally utilized in the development process. In the present study, current landuse/ landcover has been studied and for optimal utilization of the available resources, alternate landuse has been suggested using remote sensing and GIS techniques in Phakot sub-watershed for sustainable development. For this purpose multi-temporal IKONOS satellite data have been used. About 889.49 ha area out of 1466 ha of the entire sub-watershed has been suggested for alternative landuse which is 60.7% of the total geographical area of the watershed. The transformed landuse has been recommended in various prescriptions such as double cropping/intensive agriculture, agrohorticulture, agroforestry, horticulture, afforestation/forest plantations, gap filling/forest protection and land mitigation by integrating available various natural resources in the study area.

Keywords: Alternate landuse, Geographic Information System, Global Positioning System, IKONOS satellite data, remote sensing, sustainable development.

Introduction

LANDUSE refers to man's activities on earth, which are directly related to land, whereas landcover denotes the natural features and artificial constructions covering the land surface. Landuse practices of a region are influenced by a number of parameters namely physical and chemical environments, socio-economic factors and needs of the masses. Ever increasing demand due to rapid growth of population has put heavy pressure on natural resources of the country. The removal of poverty and unemployment through judicious planning and use of available resources is the hallmark of the development process. Since the adoption of the policy of planned economic development, efforts are being continually made to achieve sustainable rates of growth in all key sectors with a view to attain economic self-sufficiency and resource sustainability. To achieve such a major goal, it is imperative to have information on existing natural resource scenario, their physical/ terrain features, climate parameters, ecological conditions, socio-economic profile of the area, current practices of planning and management, and the contemporary technologies to be used for the sustainability of natural resources.

Remote sensing and Geographic Information System (GIS) techniques have capability to provide reliable information for spatial modelling so as to arrive at an alternative sustainable developmental scenario. Information on land and water resources, and their proper management are the most important components, for planning of area-specific developmental activities. For this purpose, it is essential to integrate the data on various natural resources for scientific management and optimal utilization of these natural resources[1]. The desired information could be obtained more accurately and reliably by using remotely sensed data and GIS[2–4].

In the present study, alternate landuse practices have been recommended in Phakot sub-watershed for sustainable development.

Study area

According to the AISLUS[5], Phakot sub-watershed forms a part of Huini watershed (2B5D1). The Phakot sub-watershed has been codified as 2B5D1B. It lies between lat. 30°19′57″N to 30°22′20″N and long. 78°16′52″E to 78°21′50″E and occupies an area of about 1466 ha. The study area covers parts of 53J/07 and 53J/08 topographical maps of Survey of India (SOI), on 1 : 50,000 scale. It lies at a distance of about 37 km from Rishikesh on Rishikesh–Tehri–Uttarkashi highway.

*For correspondence. (e-mail: kunwarp1@gmail.com)

Data used and methodology

In the present study, various thematic maps, viz. landuse/landcover (LULC), soils, hydrogeomorphology, slope, etc. were prepared using *rabi*, *kharif* and summer satellite data of IKONOS acquired in February 2004, October 2004 and May 2004 respectively. These maps generated from satellite data have been integrated in GIS environment using ARC/INFO software to ultimately generate/derive site-specific prescriptions for transformation of existing LULC. SOI digital toposheet on 1 : 25,000 scale, provided by the Department of Science and Technology, New Delhi, and Geographical Positioning System (GPS) were also used to prepare base map and for collection of ground truth information. SOI maps were also used in the preparation of slope map.

Results and discussions

The present study was conducted using IKONOS satellite data and GIS. Different thematic layers were generated/mapped on 1 : 4000 scale. The high-resolution satellite data have also been used earlier for mapping and extraction of features[6–8]. Existing present and recommended transformed LULC in Phakot sub-watershed is illustrated as follows.

Current landuse/landcover

Using satellite data, LULC map was prepared adopting the classification system given in the manual of nationwide landuse/landcover mapping using Satellite Imagery Parts I and II (NRSA[9]) and manual of procedure for wasteland mapping (NRSA[10]). Earlier, LULC planning and monitoring was also attempted[8,11–14]. In Phakot sub-watershed 29 LULC classes have been identified and mapped. These landuse classes fall within six broad landuse classes, i.e. built-up land, agricultural land, forests, wastelands, water bodies and others. Existing LULC in Phakot sub-watershed is shown in Figure 1. The detailed description and spatial distribution of these LULC classes are as follows.

Built-up land: Built-up land comprises towns/cities and village habitations. The extent of each inhabited area has been mapped. The geographical area of town/cities in the study area has been estimated as 0.60 ha and mainly comprises settlements of Phakot town. Settlements of other villages have been found to occupy 15.73 ha of the study area. Total built-up area has been estimated to be about 1.11% of the total geographical area of the Phakot sub-watershed.

Agricultural land: Agricultural land has been further classified into areas being cultivated only in *rabi* season (*rabi* crop), only in *kharif* season (*kharif* crop), only in summer season (*zaid* crop), cultivated in all the three seasons (triple cropped area), cultivated in any two seasons (double cropped) and fallow land. The total area under agricultural land has been estimated as 431.20 ha, which is 29.41% of the study area. Agricultural land is located on the hill slopes where terracing has been done and also in the valleys. Due to the small size of land holdings available either on the terraces or in narrow valleys, the farmers are not in a position to use modern agricultural tools and implements. The rain-fed terraces are left fallow almost every second year during the *rabi* season. Irrigated fields located in the valleys are cultivated during both the seasons and sometimes even during the *zaid* season also, where potato or other similar crops are taken. Vegetables such as tomato, ladyfinger and cucumbers are also grown in the study area.

The area sown only during the *kharif* season in 2004 was estimated as 74.23 ha, which is 17.21% of the total agricultural land in the study area. The *kharif* crops are sown in June–July and harvested in September–October. Paddy is the most important *kharif* crop, which includes several varieties sown at different times depending upon the landform and availability of water during the growing season. Maize, soyabean, *sawan*, *mandua*, *Jhangora* and *ragi* are the other *kharif* crops grown in the study area.

The area sown only in the *rabi* season was estimated as 65.31 ha which is 15.14% of the total agricultural land in the study area. The *rabi* crops are generally sown in November–December and harvested in March–April. Wheat is the most important *rabi* crop. Barley, lentil, pea, millet, potato, *masur* and mustard are the other crops grown during the *rabi* season.

The area sown only in summer season has been classified as *zaid* crop. Area estimated under *zaid* crop is 28.82 ha, which is only 6.68% of the total agriculture land in the Phakot sub-watershed. The *zaid* crop area is mainly irrigated. Potato and maize are the main crops grown during summer season.

The double cropland areas are those cultivated lands which are cultivated during two growing seasons, i.e. either *rabi* and *kharif* or *rabi* and *zaid* or *kharif* and *zaid* season. Area estimated under double cropped area is 20.11 ha, which is 4.66% of the total agriculture land. In the low hills, rice–wheat–millet–barley and millet–fallow–rice–wheat are the common two-year crop rotation. In the medium high hills, millet–fallow–rice/millet–wheat and millet–wheat–millet–fallow are the common two-year crop rotation. In the high hill areas, millet–wheat–soyabean–peas are the common two-year rotation. Rice–wheat is the most common crop rotation in double croplands areas.

The triple cropland areas are those areas which are cultivated during all the three seasons. A small part of the study area, i.e. only 0.26 ha has been found to be culti-

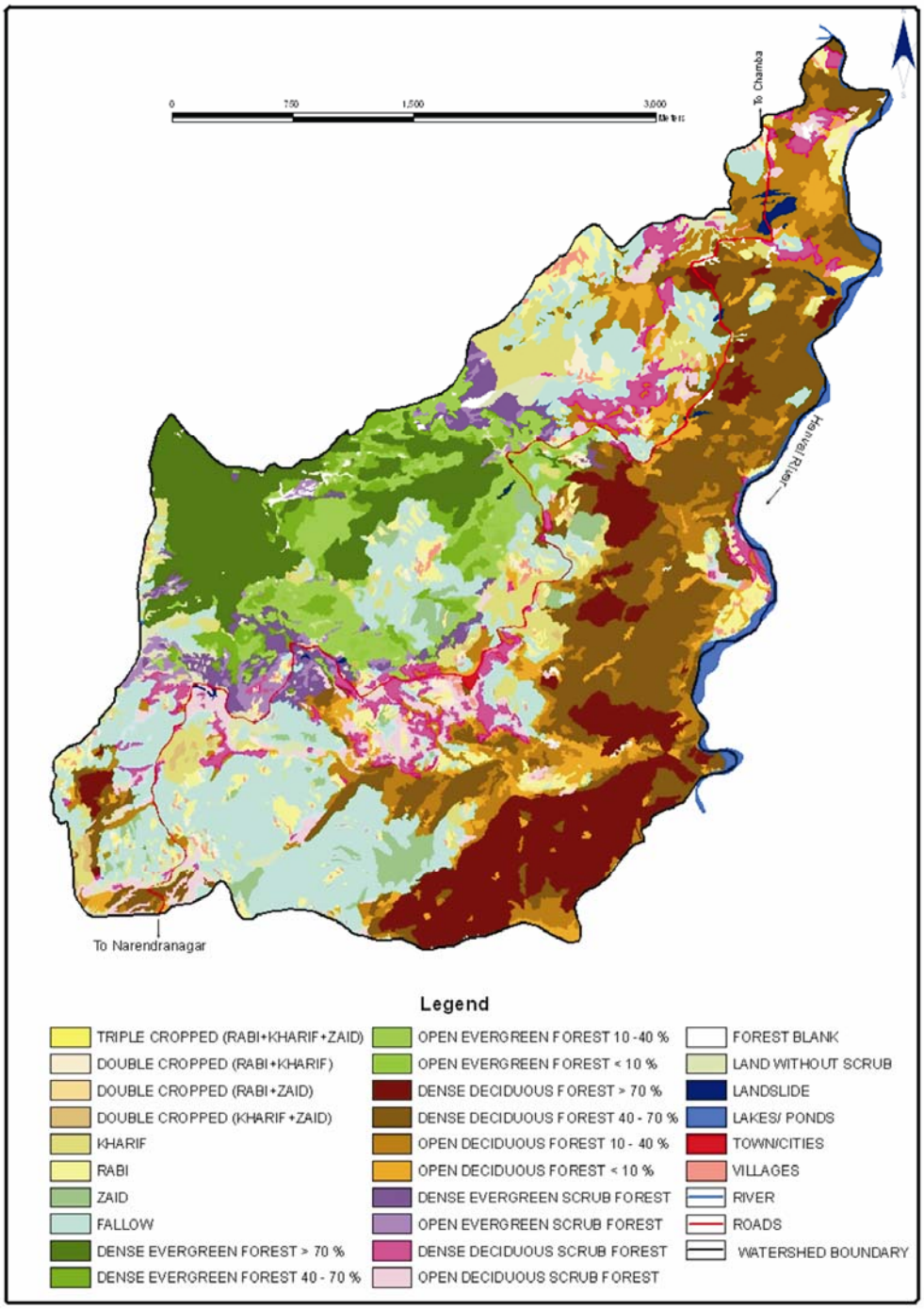

Figure 1. Current landuse/landcover map in Phakot watershed.

vated in all the three seasons. Rice, wheat, potato and maize are the most common crops in triple cropped area.

Fallow represents the agricultural land which is not cultivated during *rabi*, *kharif* or summer season. A large area, i.e. 242.48 ha has been found to remain fallow during 2004, which is 56.23% of the total agriculture land and 16.54% of the total geographical area of the Phakot sub-watershed. The area lies as fallow mainly due to non-availability of water for irrigation purpose.

Forest: The forests cover a significant portion of the study area. Both evergreen as well as deciduous types of forest are present. The species composition varies according to the altitude. Prominent evergreen species is pine. Deciduous species have also been found.

On the northern part of the hill, the forest growth is good, while on the southern part, forest growth is generally poor owing to poor soil and moisture conditions. At the higher altitude range towards northwest, most of the

forest is of evergreen nature. At the lower range of altitude, forest comprises mainly deciduous species.

The entire forest area has been classified into evergreen forest, deciduous forest, evergreen scrub, deciduous scrubs, plantations and forest blank based on interpretation of satellite data. The forest classes have been further classified into dense (>40% canopy cover), open (<40% canopy cover) based on canopy coverage. The classification of forest according to species was attempted but as the gregarious distribution of forest species does not exist in the study area, the same could not be achieved.

The total extent of forestland in the study area has been estimated as 955.15 ha, which is 65.15% of the total geographical area of study. Detailed description of various forest classes is as follows.

The evergreen forest comprises tree species most of which bear leaves throughout the year and on satellite images appear in red tone throughout the year. The main species of evergreen forest are *Quercus leucotrichophora*, *Pinus roxburghii*, *Myrica sapida*, *Pyrus pashia*, *Lyonia ovalifolia*, *Engelhardtia spicata*, *Rhododendron arboretum*, *Persea grandis*, *Prunus cerasoides*, etc. Shrub species are *Hypericum oblongifolium*, *Myrsine africana*, *Eupatorium adenophorum*, *Asparagus racemosus*, *Colebrookia oppositifolia*, *Berberis asiatica*, *Cotoneaster microphylla*, *Indigophera cassioides*, *Rubus ellipticus*, *Spermadictyon suaveolens*, *Daphne papyracea*, *Lindenbergia* spp., *Flemingia* spp., *Phyllanthus parvifolius*, *Boehmeria platyphylla*, *Artemisia roxburghiana*, etc.

Evergreen forests with a crown density of 40% and above have been classified as dense forests and those with crown density less than 40% as open forests. The area under dense forests is 153.51 ha, which is 16.07% of the total forest area. The dense evergreen forests have been further classified into crown density with 40–70% and >70%, and occupy an area of 38.72 and 114.79 ha respectively. The area under open forests has been estimated as 83.46 ha, which is 8.73% of the total forest area. The open evergreen forests have also been further identified into forest with canopy cover of 10–40% and <10% and occupy area of 70.68 and 12.78 ha respectively.

The deciduous forest comprises tree species in which leaf fall occur in the autumn and summer season, and on the satellite image of summer seasons this type of forest appears dark brown in colour. The main species in such type of forests are *Lannea coromandelica*, *Anogeissus latifolia*, *Macaranga pustulata*, *Mallotus philippensis*, *Cassia fistula*, *Terminalia alata*, *Erythrina variegata*, *Shorea robusta*, *Adina cardifolia*, *Bauhinia semla*, *Flacourtia indica*, *Terminalia bellerica*, *Terminalia chebula*, *Cassia fistula*, *Acacia catechu*, *Litsea monospetala*, *Nyctanthes arbor-tristis*, *Madhuca longifolia*, *Syzygium cumini*, etc. The associated shrubs are *Murraya koenigii*, *Lantana camera*, *Cryptolepis buchananii*, *Adhatoda zellingeriana*, *Boehmeria platyphylla*, *Rhus parviflora*, *Aerua sanguinolenta*, *Carissa opaca*, *Colebrookia oppositifolia*, *Toona ciliata*, etc.

Deciduous forests with a crown density of 40% and above have been classified as dense forests and those with crown density less than 40% as open forests. The area under dense forest has been estimated as 366.22 ha, which is 38.34% of the total forest area. The dense deciduous forests have been further classified into crown density with 40–70% and >70%, and occupy area of 225.63 and 140.59 ha respectively. The area under open forest is 191.58 ha, which is 20.05% of the total forest area. The open deciduous forests have been further categorized into forest having canopy cover of 10–40% and <10% and occupy area of 139.93 and 51.65 ha respectively.

The scrub forest constitutes a heterogeneous mixture of bushy vegetation comprising different plant species, which are classified into evergreen scrub forests and deciduous scrub forests. The evergreen scrub forests have been further divided into evergreen dense scrub forests and evergreen open scrub forests and occupy area of 36.87 and 19.84 ha respectively. The deciduous scrub forests have also been further divided into evergreen dense scrub forests and evergreen open scrub forests, and occupy area of 55.36 and 41.14 ha respectively.

Forest blanks are those areas in the notified forestland, which are completely devoid of any vegetation cover. This category occupies an area of 7.17 ha.

Available notified forest/reserved forest boundary from SOI toposheets on 1 : 50,000 scale was overlaid over landuse map. The agriculture land thus observed inside the notified forest boundary has been categorized as encroachment on forestland. An area of 17.50 ha has been estimated to be encroached by agriculture on forestland.

Wastelands: Wasteland is defined as that land which is degraded and is presently lying unutilized or under utilized outside the notified forest land, except as current fallows, due to different constraints. Only one type of wasteland, i.e. land without scrub, was found to occur in the study area, which occupies an area of 38.31 ha.

Water bodies: Water bodies include rivers, streams, lakes and ponds. Henval is the main river forming eastern boundary of the Phakot sub-watershed. Area of major rivers has been computed as 10.12 ha. There is only one pond/lake situated on top of the ridge towards western boundary of the watershed in Kasmoli village. It occupies an area of about 0.06 ha.

Other landuse/landcover categories: An area of 5.09 ha has been mapped as landslide. The main landslide has been observed on the way from Narendranagar to Tehri, which is nearer to Phakot town, and often causes blockage of roads during rainy season.

The main road is passing through the study area from Narendranagar to Tehri via Chamba. Area occupied by each LULC category is given in Table 1.

Recommended alternate/transformed landuse/landcover

The main objective of this study is to identify the problem areas and to generate site-specific LULC development plans, which indicate alternate landuse practices for optimal utilization of available resources for sustainable development. For this purpose, various thematic maps, i.e. LULC, soil (land capability), hydrogeomorphology (groundwater prospect) and slope have been integrated along with field information and collateral data. This integration is based on decision rule or key which has been developed in discussions with a team of multidisciplinary scientists, district officials and local people. LULC map has been taken as base layer and other resources maps were integrated by union in GIS envi-

Table 1. Current landuse/landcover in Phakot sub-watershed

Category	Area (ha)		
	Inside reserved forest boundary	Outside reserved forest boundary	Total
Built-up-land	0.74	15.59	16.33
Towns/cities	–	0.6	0.6
Villages	0.74	14.99	15.73
Agricultural land	17.50*	413.7	431.2
Crop land	13.13	175.59	188.72
Kharif	4.1	70.13	74.23
Rabi	7.63	57.68	65.31
Zaid	0.08	28.74	28.82
Double cropped (*Kharif* + *Zaid*)	0.27	4.62	4.89
Double cropped (*Rabi* + *Kharif*)	0.38	12.91	13.29
Double cropped (*Rabi* + *Zaid*)	0.59	1.34	1.93
Triple cropped (*Rabi* + *Kharif* + *Zaid*)	0.08	0.17	0.25
Fallow	4.37	238.11	242.48
Forests	495.91	459.24	955.15
Evergreen forest	116.54	120.43	236.97
Dense evergreen forest >70%	78.02	36.77	114.79
Dense evergreen forest 40–70%	16.12	22.6	38.72
Open evergreen forest 10–40%	19.6	51.08	70.68
Open evergreen forest <10%	2.8	9.98	12.78
Deciduous forest	352.97	204.83	557.8
Dense deciduous forest >70%	114.32	26.27	140.59
Dense deciduous forest 40–70%	154.35	71.28	225.63
Open deciduous forest 10–40%	63.3	76.63	139.93
Open deciduous forest <10%	21	30.65	51.65
Scrub forest	19.23	133.98	153.21
Dense evergreen scrub forest	6.82	30.05	36.87
Open evergreen scrub forest	2.88	16.96	19.84
Dense Deciduous scrub forest	6.71	48.65	55.36
Open deciduous scrub forest	2.82	38.32	41.14
Forest blank	7.17	–	7.17
Wastelands	–	38.31	38.31
Land without scrub	–	38.31	38.31
Water bodies	7.26	2.92	10.18
River/stream	7.26	2.86	10.12
Lakes/ponds	–	0.06	0.06
Others	2.37	12.46	14.83
Landslide	1.53	3.56	5.09
Roads	0.84	8.9	9.74
Total area	523.78	942.22	1466

*Agricultural land as encroachment forest land based on available reserved forest boundary taken from 1 : 50,000 SOI toposheets.

Table 2. Area statistics of transformed landuse practices suggested in Phakot sub-watershed

Transformed landuse	Current landuse/landcover	Area (ha)	Area (%)
Double cropped		14.00	0.95
	Kharif	0.79	0.05
	Rabi	13.09	0.89
	Zaid	0.12	0.01
Agrohorticulture		151.50	10.33
	Kharif	15.75	1.07
	Rabi	18.33	1.25
	Zaid	14.73	1.00
	Fallow	102.69	7.00
Agroforestry		245.34	16.74
	Kharif	57.69	3.94
	Rabi	33.89	2.31
	Zaid	13.97	0.95
	Fallow	139.79	9.54
Horticulture		3.71	0.25
	Open evergreen scrub forest	0.04	0.00
	Open deciduous scrub forest	0.18	0.01
	Land without scrub	3.49	0.24
Afforestation/forest plantation		259.41	17.70
	Dense evergreen scrub forest	36.87	2.52
	Open evergreen scrub forest	19.80	1.35
	Dense deciduous scrub forest	55.36	3.78
	Open deciduous scrub forest	40.96	2.79
	Forest blank	7.17	0.49
	Land without scrub	34.82	2.38
	Open evergreen forest <10%	12.78	0.87
	Open deciduous forest <10%	51.65	3.52
Gap filling/forest protection		210.44	14.35
	Open evergreen forest 10–40%	70.68	4.82
	Open deciduous forest 10–40%	139.76	9.53
Landslide mitigation		5.09	0.35
	Landslide	5.09	0.35
No action		576.51	39.33
	Triple cropped	0.25	0.02
	Double cropped (*Kharif* + *Zaid*)	4.89	0.33
	Double cropped (*Rabi* + *Kharif*)	13.29	0.91
	Double cropped (*Rabi* + *Zaid*)	1.93	0.13
	Dense evergreen forest >70%	114.79	7.83
	Dense evergreen forest 40–70%	38.72	2.64
	Dense deciduous forest >70%	140.59	9.59
	Dense deciduous forest 40–70%	225.63	15.39
	Open deciduous forest 10–40%	0.17	0.01
	Lakes/ponds	0.06	0.00
	Town/cities	0.60	0.04
	Village	15.73	1.07
	River	10.12	0.69
	Roads	9.74	0.66
Total area		1466.00	100.00

ronment. All the sub-optimally utilized and wasteland classes were then identified and suggestive measures were recommended to transform/alternate LULC. The transformed landuse plan thus prepared was also verified in the field. Integrated approach using GIS and remote sensing techniques has been successfully applied earlier for transformation of LULC by many researchers[1,15–18].

Various activities suggested for land resources management plan and their area in Phakot sub-watershed are given in Table 2. About 889.49 ha area has been found to be sub-optimally utilized or laying waste for which alternate landuse practices have been recommended to utilize this land to its full potential. Thus, about 60.67% of the total geographical area of the watershed has to be trans-

formed for alternate landuse planning for sustainable land resources development. Alternate landuse practices suggested for the study area are as follows.

Double cropping/intensive agriculture: Double cropping has been recommended where existing agriculture land is cultivated for a single crop but the land capability class is I or II, such area could be taken up for double crop after providing suitable source of irrigation. About 0.79 ha of *kharif* crop area, 13.09 ha of *rabi* crop area and 0.12 ha of *zaid* crop area have been recommended to be transformed into double cropping area. Thus, about 14.00 ha area has been recommended for double cropping, which is 1.57% of the total area recommended for various developmental activities in the study area.

Agrohorticulture: Agrohorticulture practices are suggested for existing hill terraces used for agriculture and situated on north-west, north-east, north and western part where the shadow of fruit trees are expected to fall along terrace slopes and not on the main crop land. Some wasteland area is also recommended for agrohorticulture where land capability class is I or II after suitable arrangement for irrigation and terracing. The fruit trees have been suggested to be planted along the terrace slope. Due to uncertainty of crop survival, growing suitable fruit trees with existing crop in such areas would not only supplement the income to the farmers but will also arrest soil erosion. The tolerance of fruit trees towards monsoon aberration is also much better than short duration crops, thus can utilize off-season rains and soil moisture from deeper layers. Type of horticulture plants to be planted in these areas could be selected on the basis of site conditions and choice of the local people. Some of the plants suitable in this area are *Prunus persica* (Peach), *Prunus armeniaca* (Apricot), *Juglans regia* (Walnut), *Castanea sativa* (Chestnut), *Pyrus communis* (Pear), *Malus pumilo* (Apple), etc. About 151.50 ha of land area in the watershed has been recommended to be used for agrohorticulture which is 17.03% of the total area recommended for management plan activities. The above alternate landuse practice has been suggested by transforming current landuse of *kharif* crop (15.75 ha), *rabi* crop (18.33 ha), *zaid* crop (14.73 ha) and fallow land (102.69 ha).

Agroforestry: Agroforestry system has been suggested to meet the needs of local people for fuel and fodder in addition to agriculture crops. Agroforestry has been suggested on those hill terraces, which are currently under cultivation, and lies on south-east, south-west, south and eastern parts. Some wasteland areas are also recommended for agroforestry where land capability class is I or II after terracing and suitable arrangement of irrigation. The fuel and fodder trees could be planted along terrace slope. The soil on these terraces is relatively poor and has relatively low soil moisture. These trees, once established, will have greater tolerance towards drought conditions and will cater towards fuel and fodder requirement besides checking the soil erosion and enhancing groundwater recharge. An area of 245.34 ha has been recommended for agro-forestry, which is 27.58% of total recommended area and transformed from current landuse practice of *kharif* crop (57.69 ha), *rabi* crop (33.89 ha), *zaid* crop (13.97 ha) and fallow land (139.79 ha). Some of the fuel and fodder tree species to be considered for agroforestry are *Alnus nepalensis*, *Quercus leucotrichophora*, *Grewia oppositifolia*, *Fraxinus excelsior*, *Ficus aurantiaca*, *Bauhinia racemosa*, *Bridelia retusa*, *Bauhinia purpurea*, *Robinia* spp., *Celtis australis*, *Hoyenia dulcis*, etc.

Horticulture: Wasteland and long fallow land with suitable soils, slopes, etc. mainly on north-west, north-east, north and western parts in the vicinity of road network have been recommended for horticulture. An area of 0.04 ha of open evergreen scrub forest, 0.18 ha of open deciduous scrub forest and 3.49 ha of land without scrub under current landuse have been recommended for horticulture purpose which has a total area of 3.71 ha. Depending upon site conditions and choice of the local people, suitable fruit tree could be planted in these areas. Some of the plants suitable for this area are *Prunus persica* (Peach), *Prunus armeniaca* (Apricot), *Juglans regia* (Walnut), *Castanea sativa* (Chestnut), *Pyrus communis* (Pear), *Malus pumilo* (Apple), etc. Plantations for sericulture could also be raised in these areas depending upon site condition, which require detailed investigations.

Afforestation/forest plantations: 12.78 ha of open evergreen forest with crown density <10%, 51.65 ha of open deciduous forest with crown density <10%, 36.87 ha dense evergreen scrub, 19.80 ha open evergreen scrub, 55.36 ha dense deciduous scrub, 40.96 ha open deciduous scrub, 7.17 ha forest blank and 34.82 ha of land without scrub, other than that recommended for horticulture, agrohorticulture and agroforestry, have been recommended for afforestation/forest plantations. Thus, a total of about 259.41 ha of the land have been recommended for landuse transformation under this category, which is 29.16% of total area recommended for activities under the management plan. Some of the tree species suitable for afforestation in the study area are *Pinus roxburghii*, *Rhododendron arboretum*, *Holoptelea integrifolia*, *Alnus nepalensis*, *Syzygium cumini*, *Bauhinia parpuria*, *Myrica spida*, *Toona ciliata*, *Quercus leucotrichophora*, *Pyrus pashia*, *Lyonia ovalitolia*, *Engelhardtia spicata*, *Lannea*, *Coromandeliea*, *Anogeissus latifolia*, *Teminalia olata*, etc. However, selection of trees should be made at the time of action plan implementation from local species based on the actual site conditions.

Gap filling/forest protection: About 210.44 ha area has been recommended for landuse transformation under

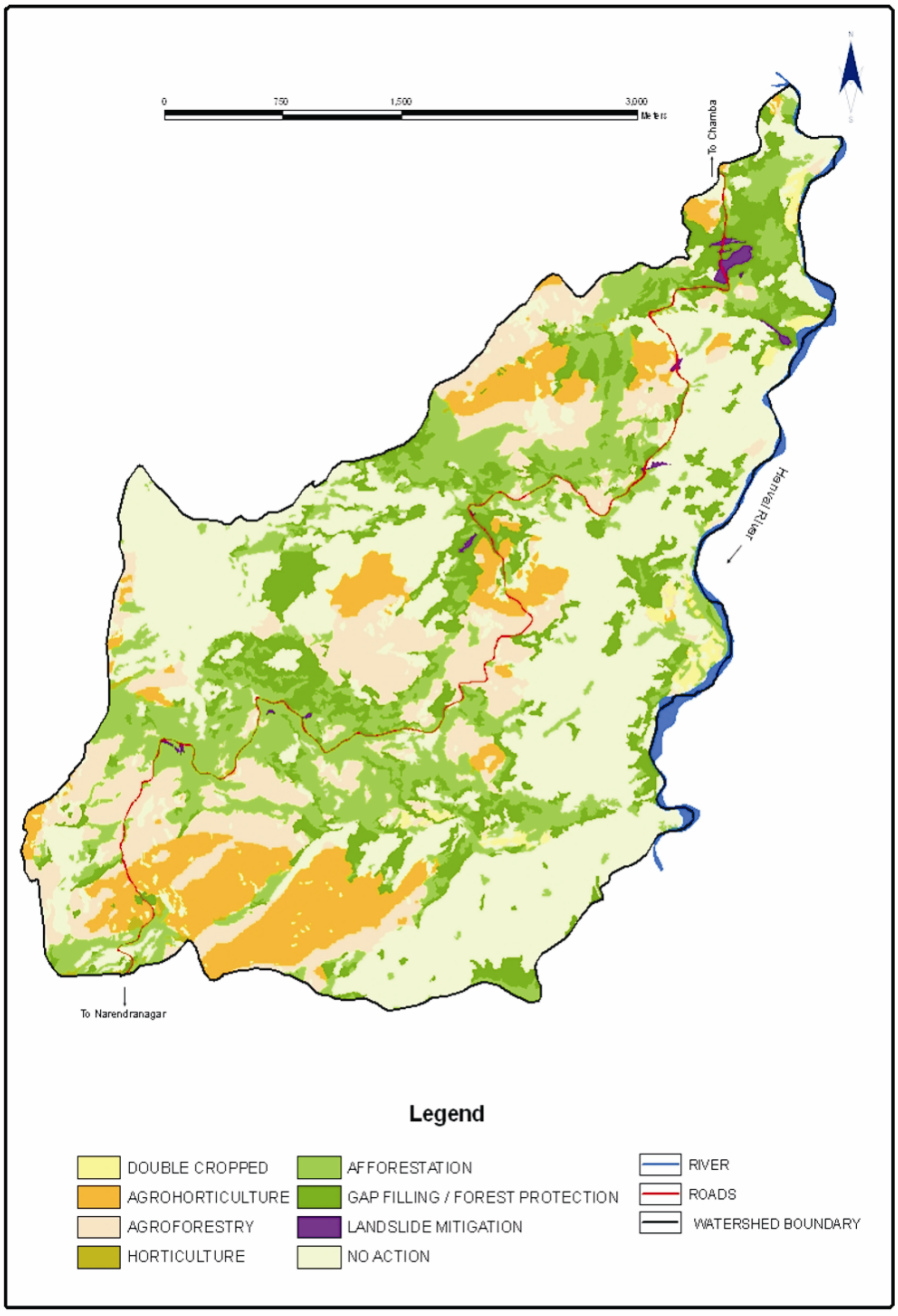

Figure 2. Transformed landuse practices suggested in Phakot watershed.

this category, which is 23.66% of the total area recommended for the management plans. Current landuse categories, which have been suggested for alternate landuse practice, are open evergreen forest with 10–40% density (70.68 ha) and open evergreen forest with 10–40% density (139.76 ha). Tree species recommended above may be selected according to the suitability of site for plantation in the gaps. Moreover, it is also proposed that such forest areas, having relatively high crown density and where the afforestation by way of gap filling is difficult, may be totally protected from biotic interference by suitable means to allow natural regeneration.

Landslide mitigation: An area of about 5.09 ha has been identified as landslide in the Phakot sub-watershed. These areas require to be protected both through suitable soil conservation measures as well as by suitable protective structures.

Figure 2 represents suggestive transformed landuse, in order to optimally utilize land resources so that sustainable development could be achieved.

Conclusions

Scientific integrated approach is required for sustainable development of a region. The data-gathering capabilities of space-borne remote sensors have now been well established for continuous monitoring and management of natural resources. The management plans, which have been prepared by suggesting alternate use of the land, would lead to optimal utilization of land resources and ultimately sustainable development of the area.

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