Assessing the land cover situation in Surkhang, Upper Mustang, Nepal, using an ASTER image

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This paper describes the remote sensing technique used to prepare a land cover map of Surkhang, Upper Mustang Nepal. The latest ASTER image (October 2002) and an ASTER DEM were used for the land cover classification. The study was carried out in Surkhang Village Development Committee (area 799 km^2) of Upper Mustang region. The study area falls within the Annapurna Conservation Area. Field surveys for training data, ground truthing and spectral signature collection were carried out during May-June 2002. Various image classification algorithms were tested, and the one that yielded the best result was used for image classification. The land cover situations with their aerial extents were identified and topographic analysis was carried out to study the variations of different land covers types in the region. Various species of grasses covered about 36 %; shrubs covered about 32%; bare land, which includes area from completely bare to less than 10% vegetation, constituted about 20% of the land resources of the study area. Grassland was found abundant in east- to south-facing slopes, while shrub species were abundant in flat regions and west- to north-facing slopes.

Key words: ASTER image, DEM, land cover mapping, Mustang, Nepal, GIS, remote sensing

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Introduction

Land cover maps record the structure and make-up of a landscape. A map structure related directly to real features on the ground can help to understand and interpret the environment. It shows the inter-connectivity of landscape features, their immediate context and the wider neighborhood in which environmental influences operate. This type of map helps to see how ecological principles can explain patterns of landscape diversity.

Recent improvements in satellite image quality and availability have made it possible to perform image analysis at much larger scale than in the past. This will likely lead to a wider use of satellite imagery at the regional level as a reliable source of timely and accurate spatial data. In recent years, Geographic Information System (GIS) technologies have greatly increased ability to map and model land cover, providing resource managers and researchers with a tool to analyze data and address specific problems at a variety of spatial scales, in less time, and in a more cost-effective manner (Ramsey et al. 1999).

Land cover classification involves grouping of components into homogeneous units on the basis of characteristics significant to the management of land resources. Through remote sensing techniques supplemented with field surveys, an accurate land cover map can be prepared in cost effective manner than manual survey land cover mapping, and both biotic and abiotic surface features, including vegetation composition and/or density and local landforms, can be interpreted (Best 1984).

The changing land cover conditions can be quantified using change detection remote sensing techniques. Remote sensing techniques, together with ground truth data, are widely used to collect information on the qualitative and quantitative status of natural resources in protected areas. With the advent of satellite technology and GIS, it has been now well-accepted tools to establish and model spatial information (Mongkolsawat and Thirangoon 1998).

Satellite imagery interpretation is one way of obtaining information on land use resources that has also been emphasized in the Management Information Systems (MIS) plan of the Annapurna Conservation Area Project (ACAP) (Chapagain 2001). Once these resources are assessed and integrated with other bio-physical and socio-economic information of management relevance, land cover mapping being an activity for resource assessment, the MIS would support decision making in the project area. This study was carried out with the objective of assessing land resources in the Upper Mustang Biodiversity Conservation Project (UMBCP) of King Mahendra Trust for Nature Conservation (KMTNC) and preparing an accurate and up-to-date land cover map of Surkhang, Upper Mustang.

Materials and methods

Study area

The study was carried out in Surkhang, the largest of the seven Village Development Committees (VDCs) in Upper Mustang (In Nepal the VDC is the smallest administrative unit.) The geographic coverage ranges approximately from 28^{0}50'19"-29^{0}09'10" N and 83^{0}49'41"-84^{0}15'16" E. The land cover classification and mapping for this VDC was carried out over an area of about 784 km^2; the remaining 15 km^2 was not included in this research due to unavailability of satellite data. This VDC borders on Tibet in the east, and is one of the most remote areas of Nepal **(Plate 1)**.

The region is situated in the Himalayan rain shadow and ➔

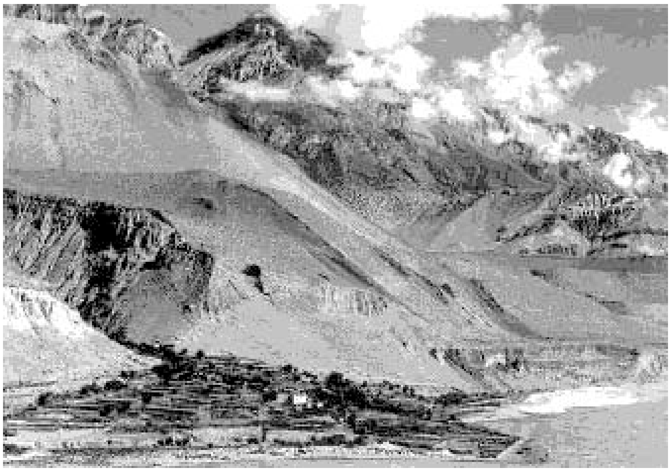

PLATE 1. A landscape view of Upper Mustang

receives less than 100 mm rainfall annually (HMGN 1999). More than 40 percent of Mustang's area is rangeland and pasture at altitudes of 3,000 to higher than 5,000 m asl (Blamont 1996); the elevation of our study area ranges from 3000 to more than 6000 m asl. The whole VDC remains under snow for 4-5 months (November to March). The Upper Mustang region is said to be the southern extension of the Tibetan plateau. The climate and landscape of Upper Mustang are similar to that of Tibetan plateau. Alluvial fans, jutting sandstone ridges, abandoned glacial moraines and broad sandy terraces are among the more conspicuous elements of this highly accidented landscape. Mean annual daytime temperatures are around 21°C, but mean annual nighttime temperatures may fall to 5°C. Only herders and pastoralists visit the northern area of this VDC, often for 2-3 months in summer **(Figure 1)**.

Remote sensing data

A surface radiance image of Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) taken on October 2002 and ASTER Digital Elevation Model (DEM) (ASTER 2001) were used for the land cover classification. ASTER covers a wide spectral region with 14 bands from visible to thermal infrared with high spatial, spectral and radiometric resolution. An additional backward-looking near-infrared band provides stereo coverage (Abrams and Hook 2001), which is generally used for the preparation of DEM. The spatial resolution varies with wavelength: 15 m in the visible and near-infrared (VNIR) region, 30 m in the short wave infrared (SWIR) region, and 90 m in the thermal infrared (TIR) region. This ASTER image was geo-referenced with the help of topographic maps of the study areas by locating 18 conspicuous ground control points (GCPs), such as ridges and confluences. For the sake of computational simplicity, a first order polynomial transformation with the nearest neighbour resampling technique was used (Lillesand and Kiefer 2000); this entailed directly assigning the digital number (DN) in the input file that overlaps the pixel in the output file, avoiding the necessity of altering the original input pixel values (Richards 1993). For the analysis a spatial resolution of 30 m was used. The root mean square error was 0.21 pixels.

Although the original ASTER image had 14 bands, for this study only nine bands covering visible to short wave infrared were used. The thermal bands were not used because of their coarse resolution (90 m).

The image acquisition date was in winter when the cultivated fields of Upper Mustang were devoid of crops. The roofs of houses in UM regions are made mostly of mud. The agricultural fields are found in the surrounding of houses. The field survey phase identified that in winter the vegetation cover on agricultural fields was limited to grasses and shrubs, and many were completely barren. Such fields were not correctly distinguished as a separate class in satellite images. Therefore, cultivated areas were digitized from topographic maps. Eleven such agricultural areas were identified on the available topographic maps. These fields were masked in the original image and excluded from classification. For statistical estimates and map preparation, these areas were reincorporated into the classified image.

Principal components analysis (PCA) allows compaction of redundant data into fewer bands thereby reducing the dimensionality. The bands of PCA data are noncorrelated and independent, and are often more interpretable than the source data, yielding better classification results (ERDAS Inc 1999). Nine principal components were derived from the original 9 bands of the ASTER. The information contained in each component was checked and the components containing most information were used for the analysis.

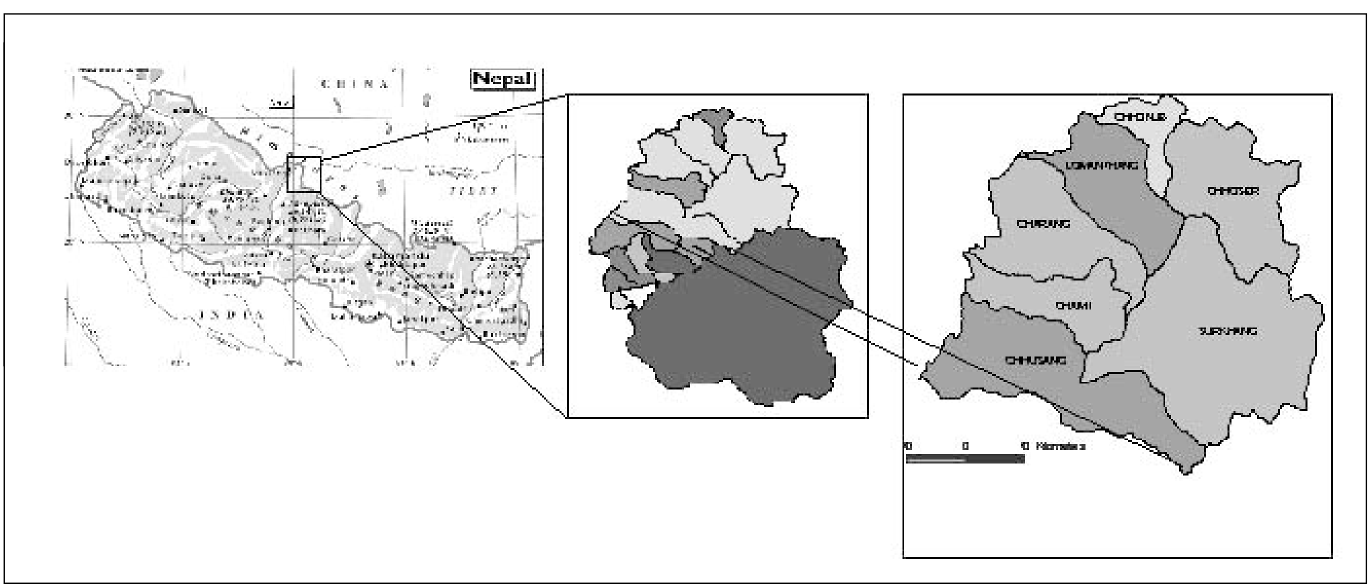

FIGURE 1. Map of the study area: Nepal (left), Annapurna conservation area showing the different VDCs of Mustang (middle) and Upper Mustang showing Surkhang, the study area (right)

BOX 1. Description of land cover classes used to classify the study area

Cover class	Description
Agriculture and settlement	This class includes villages and community settlements, as well as adjoining crop fields and tree stands. Usually trees and crop fields are along the periphery of clustered houses. Almost all of this class lies along riverbanks. This is the pattern of settlement throughout the Upper Mustang region.
Bare land	This class includes the land surface with little or no cover (i.e. less than 10% vegetation cover). The region of rock-falls is also included in this class.
Water bodies	Rivers, streams, and rivulets constitute this class. Lakes formed by glaciers are frequently found above 5000 m elevation. Perennial rivers, glacial lakes and permanent water bodies are included in this class while the small rivers which remained dry during the time of image acquisition are not included
Grassland	This is the most prevalent land cover of the area, usually above 4000 m. All high altitude pastures with smooth slopes consist of alpine grasses. The habitat is highly favored by blue sheep and other grazers.
Shrub land	This is the second most prevalent land cover class above 3000 m. *Lonicera obovata* and *Caragana* spp. dominate this class, associated in some locales with *Berberis* spp.
Snow cover	This class includes those peaks with permanent snow cover. They are usually found above 6000 m elevation.

The normalized difference vegetation index (NDVI) is calculated from the reflected solar radiation in the near-infrared (NIR) and red (RED) wavelength bands via the algorithm.

The NDVI is a nonlinear function, which varies between –1 and +1 but is undefined when RED and NIR are both zero. The NDVI can be used as an indicator for the amount of green biomass. It is used to discriminate vegetated and non-vegetated regions in image analysis to improve classification results.

Aspect in general has greater significance in vegetation characteristics as it determines the amount of radiation available for the plant. Around the world, aspect and slope are used as predictors of vegetation types (Hamilton et al. 1997). The aspect and slope images were derived from the available DEM and used to test if they contribute significantly in cover type discrimination.

A review of studies carried out by Koirala and Shrestha (1997) and Raut (2001) were undertaken in order to obtain a general picture of land cover classes of the region. Taking into consideration these earlier studies as well as the feasibility of cover discrimination by image analysis, we developed a classification scheme **(Box 1)**.

An unsupervised classification, the iterative self-organizing data analysis (ISODATA) clustering algorithm, which operates by initially seeding a specified number of cluster centroids in spectral feature space (Debinski et al. 1999), was used to get an idea of possible cover classes of the region. It served as an aid for the supervised classification and selection of appropriate sites during the training stage.

Supervised classification is an essential tool for extracting quantitative information from remotely sensed image data (Richards 1993). For this technique, a number of mathematical approaches have been developed (Lillesand and Kiefer 2000). We tested four common algorithms on the first 3 bands (in VNIR region) of the ASTER image: minimum distance to mean (MDM), mahalanobis distance (MHD), parallelepiped (PPL) and maximum likelihood (MLH). The algorithm that gave best results in terms of accuracy was chosen for the final classification.

Training data were collected in order to obtain good representatives of each vegetation type (Lillesand and Kiefer 2000). Field observations, aerial photographs, topographical maps, Global Positioning System (GPS) survey and the image of the unsupervised classification were used to collect data from 70 training sites, which included all types of land cover designated for the work. Spectral signatures were collected from a wide range of elevations (3000 to 5600 m asl). Signatures were also collected from sites with differences in topographic slope and aspect in order to normalize differences in radiance. Two sets of data, one for the classification and another for the evaluation of the classified image, were collected.

The collected spectral signatures were evaluated by plotting the mean spectral signature and checking if the classes could be discriminated using the given set of bands in the image. We also plotted the signature ellipses in the feature space. The spectral mean plot was calculated for a composite of 17 bands: 9 original ASTER bands, 4 PC bands, DEM, slope, aspect and NDVI image. This helped to determine which bands to include for the classification.

Results and discussion

Results of principal component analysis

PC 1 contained 80% of the information of the 9 original ASTER bands. The combination of 4 principal components constituted more than 99% of the information **(Table 1)**. This means that 4 PCs can give 99.89% of the information that the 9 original bands could do. Therefore these 4 bands were used to determine the optimum band combination for land cover classification.

Obtaining an optimum number of land cover classes

The results of the classified image of the unsupervised (ISODATA) classification were used to create a histogram. The result of the histogram is presented in the form of a line graph of the classes **(Figure 2)**. If a sharp decrease is present in the histogram, it could represent the point where additional clusters are irrelevant (Tatham and O'Brien 2001). Since there is a sharp fall in the number of pixels

TABLE 1. Principle components (PC) and % information contained

PC	% explained variance	Cumulative %
1	80.66	80.66
2	18.57	99.23
3	0.55	99.77
4	0.11	99.89
5	0.06	99.95
6	0.02	99.97
7	0.02	99.99
8	0.01	99.99
9	0.01	100

after the seventh class, it is concluded that seven classes would be sufficient. However, during the field survey and ground truthing work it was found appropriate to make a land cover map comprising only 6 classes (as per the management relevance of the scope of this work) **(Box 1)**.

Spectral signature evaluation

The spectral signatures of five classes (excluding agriculture and settlements) were plotted against the 17 bands to evaluate and determine which band combinations could best discriminate the cover classes **(Figure 3)**. Bands 3, 5, 7, 8 and 9 could easily discriminate the classes. PC 1 can discriminate the classes as well. Aspect and NDVI image could discriminate the vegetated classes from the non-vegetated ones. The PC 1 image, which contains only 88.66% of the information of the original 9 bands, could differentiate the cover classes better than original 1, 2, 4, and 6 bands. We tested our hypothesis that the inclusion of this PC 1 image could compensate for the loss of information of the excluded bands 1, 2, 4 and 6. A combination including PC 1 and another combination without PC 1 were compared to find out if this hypothesis was valid.

Use of DEM as a separate band did not give usable results. In the spectral plot, the DEM could discriminate the classes, but that is not meaningful as the values are the locations of the pixel for which the classes were taken. Eiumnoh and Shrestha (1997) reported that DEM enhanced the classification techniques in their studies. An unsupervised classification was run in the original bands with DEM and the result was not as expected. Rather, the inclusion of DEM as a separate band resulted in a rough classification of elevation zones in the image.

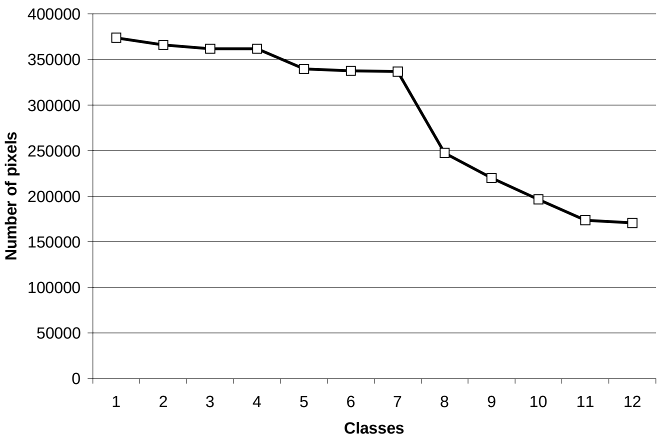

FIGURE 2. Line graph of histogram analysis of 12 clusters (results of ISODATA unsupervised classification)

Selection of appropriate classifier

The results of supervised classification carried out over the three bands (in VNIR region to test the classification algorithms) using four different classification algorithms **(Table 2)**. These accuracy assessments were done by using an independent set of ground data i.e., other than that used for classification.

Among these 4 tested classifiers, the maximum likelihood classifier gave superior results in terms of accuracy. Therefore, this

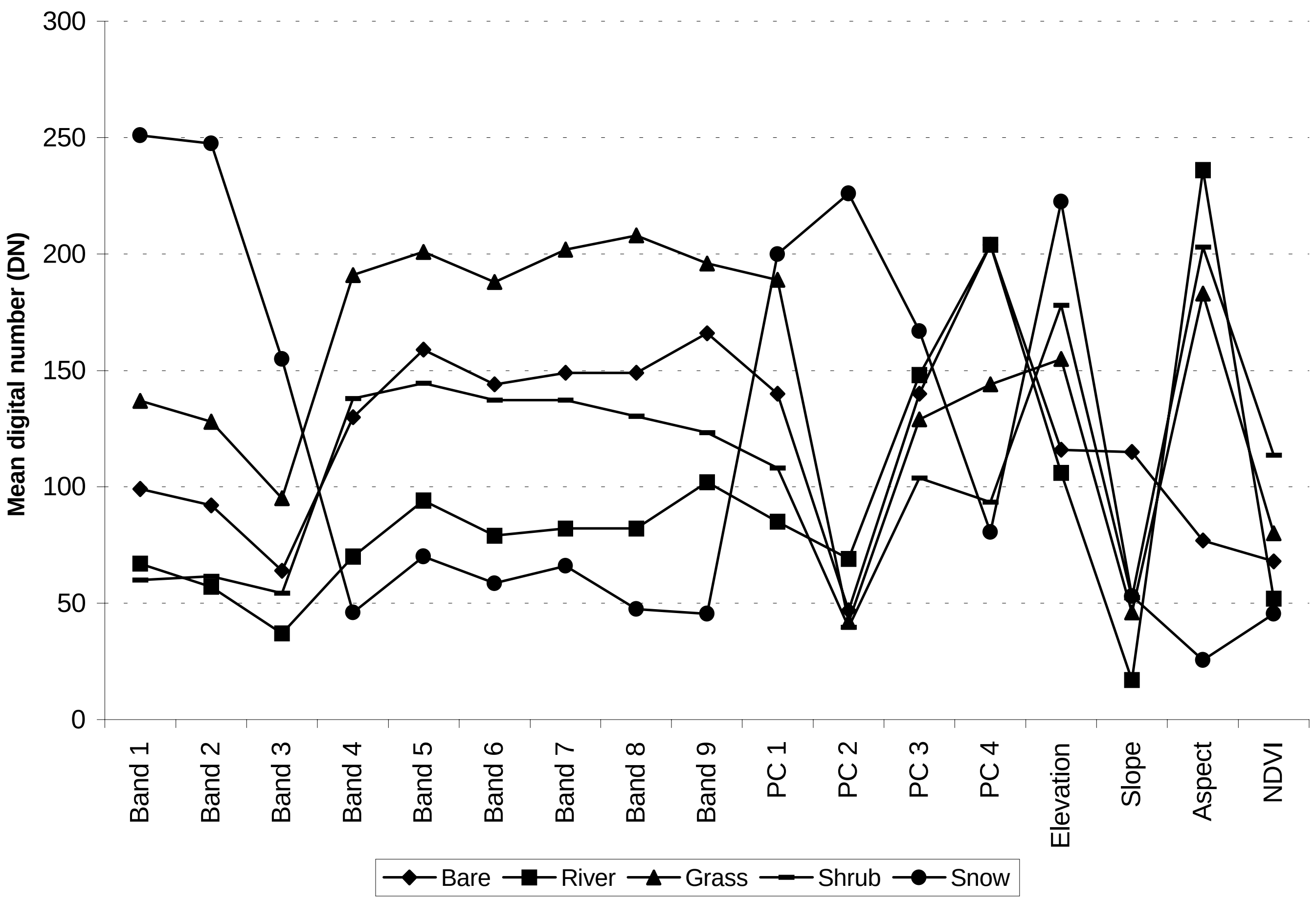

FIGURE 3. Spectral signatures mean plot of the classes

classifier was used for all subsequent studies including the final classification.

Selection of appropriate band combinations for classification

Detailed analysis of the available spectral and DEM information showed that 4 combinations were promising for discriminating the six classes (Sharma 2003). To find out the most suitable bands for classification, these combinations were classified using maximum likelihood classifier with a 95% confidence interval. The results in terms of classification accuracy for the bands tested are given in **Table 3**.

Since the classification of BC 4 which constituted bands 3, 5, 6, 7, 8, 9, NDVI and aspect gave the best overall classification accuracy, this combination was used for final classification. The users' and producers' accuracy are given in **Table 4**. It was found that the inclusion of PC bands when other original bands suffice to discriminate the classes did not enhance the classification accuracy.

A 3 by 3 majority filter was applied in order to smoothen the salt-and-pepper appearance in the classified image according to the methods and rational described by Eastman (1997). The land cover map and its information are presented in **Figure 4** and **Table 5** respectively.

Vegetation patterns and their characteristics in Upper Mustang

The spatial analysis carried out using GIS showed that the agriculture and settlement class was found between 3036 and 4212 m asl. Cultivated fields and settlements were scattered and constitute only a small portion of the total land cover in the region. Snow was observed at elevations as low as 5172 m asl. Grasslands were found up to 7101 m asl, while shrub lands were found up to 7166 m asl. (Interpretation of the values related to elevation should take into account the release notes of DEM given in ASTER 2001).

In the study of the general distribution of vegetation in the study area by aspect, grass species which were generally more light-demanding were found primarily on east- to southwest-facing slopes, while shrub species, which are shade tolerant, were found on cooler north-, west-, and northwest-facing slopes, which received fewer hours of sunlight **(Figure 5)**.

The NDVI analysis showed that the shrub lands had higher biomass (NDVI values) than grasslands. The NDVI, which varies between -1 and +1 in general, was found to be between -0.46 to 0.32 for shrub land and -0.34 to 0.23 for grassland. The NDVI image within each of the grassland and shrub land was classified into 3 classes to represent low, moderate and high density. The results showed that the study area contained, for the most part, a low density of grasslands and a moderate density of shrub land **(Table 6)**.

Conclusions

A classification of land cover with a high level of accuracy was obtained from an ASTER image with maximum likelihood classifier. Inclusion of ancillary data such as NDVI and aspect images increased the classification accuracy. Based on the October 2002 image, we found that cultivated land and settlements cover 0.31%, bare land 20.19%, water bodies 1.82%, grassland 36.01%, shrub land 32.57% and snow 9.11% of the total area of Surkhang. Grass species were abundant in east- to south-facing slopes while shrub species were abundant in flat and west- to northwest-facing slopes. The vegetation analysis showed that Surkhang contains a low density of

TABLE 2. Classification accuracy of different classifiers

SN	Classification algorithm	Overall accuracy
1	Minimum distance to mean (MDM)	64.38 %
2	Mahalanobis distance (MHD)	66.93 %
3	Parallelepiped (PPL)	62.03 %
4	Maximum likelihood (MLH)	67.44 %

TABLE 3. Description of band combinations (BC) and the accuracy obtained

Band combination	Constituent bands	Overall accuracy
1	Bands 1, 2, 3, 4, 5, 6, 7, 8, 9	77.78 %
2	Bands 1,2,3, 4, 5, 6, 7, 8, 9 and Aspect	79.07 %
3	Bands 3, 5, 7, 8, 9, PC1, NDVI and Aspect	91.73 %
4	Bands 3, 5, 7, 8, 9, NDVI and Aspect	92.25 %

TABLE 5. Area of land cover classes

Class	Percent	Area (km^2)
Agriculture and settlements	0.31	2.44
Bare land	20.19	158.31
Water body	1.82	14.25
Grassland	36.01	282.34
Shrub land	32.57	255.38
Snow cover	9.11	71.40
Total	100.00	784.11

TABLE 6. NDVI characteristics of two vegetation types

Category	Grassland		Shrub land	
	NDVI	%	NDVI	%
Low	-0.345 to -0.152	68.36	-0.462 to –0.20	4.78
Moderate	-0.152 to 0.041	31.62	-0.20 to 0.062	91.67
High	0.041 to 0.234	0.01	0.062 to 0.324	3.55

TABLE 4. Producers' and users' accuracy of classified image using BC 4

Class name	Reference total	Classified total	Number correct	Producers accuracy	User's accuracy
Bare land	104	102	97	93.27%	95.10%
Water bodies	30	32	28	93.33%	87.50%
Grassland	99	118	97	97.98%	82.20%
Shrub land	92	73	73	79.35%	100.00%
Snow cover	62	62	62	100.00%	100.00%
Totals	387	387	357		

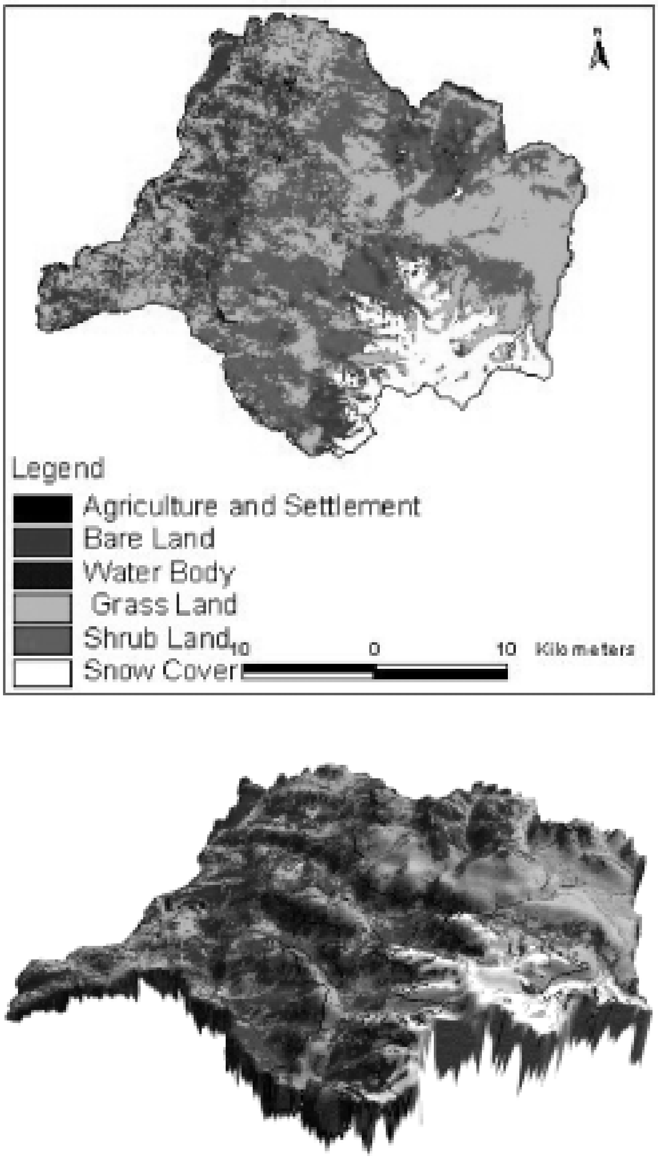

FIGURE 4. Land cover map of Surkhang (upper) and a 3 dimensional perspective view created by draping the land cover map over the Digital Elevation Model of the of the same study area (lower)

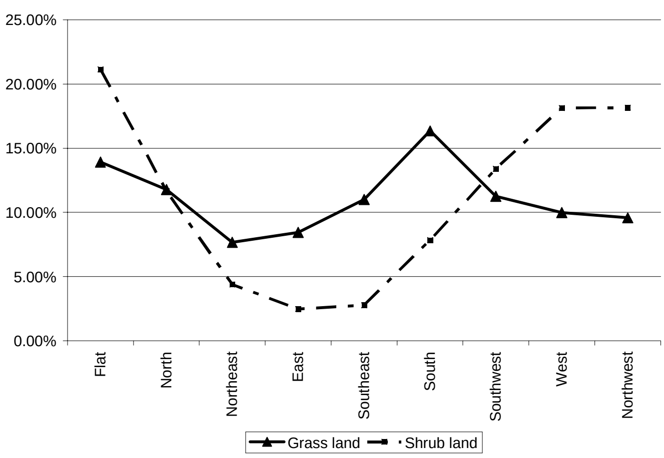

FIGURE 5. The distribution of vegetation at different aspects

grass species and a moderate density of shrub species. The output of this study is the data regarding land cover and spatial relationships, which may contribute to any spatial analysis related to the study area for the Management Information Systems. ■

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