Relationship among environmental parameters (Physiognomic factors) and land cover in the Simen Mountains National Park, Ethiopia

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Abstract

Environmental parameters (mainly altitude, aspect and slope) are responsible for distribution of land cover types. This paper shows the relationship of land cover distribution across environmental parameters through interpretation of satellite image of 2003 using the tools of GIS and remote sensing (RS). Digital elevation model (DEM) was used to generate elevation information and to georeference the Landsat image. With GIS and Remote Sensing land cover (LC) can be drawn and can have a potential for mapping the wildlife habitat and biodiversity in the park. Moreover, spatial analysis (using RS and GIS) are needed to support and get quick and economical acquisition of a vegetation map or LC with an appropriate balance between data accuracy and reasonable cost. Results of the satellite image analysis showed that forest cover is higher in steeper terrains; and agriculture and grassland are dominantly found above 3000m above sea level.

Key words: DEM, Environmental parameters, GIS, SMNP

Introduction

There are two major (primary) methods for capturing information on land cover (LC) or land cover change (LCC): direct field survey, and analysis of remotely sensed imagery (http://en.wikipedia.org/wiki/Land_cover 19/03/2007). GIS and remote sensing are important tools to understand various natural processes and socioeconomic situations both in space and time. GIS is a set of tools for collecting (acquiring), storing, analyzing, and displaying (visualizing) the spatial information. Particular uses of GIS comprise infrastructure and facility planning, land use planning, monitoring and assessment of environmental conditions, hazard mapping, urban change, land cover change (LCC), trend analysis of environmental alteration. With particular reference to land cover (LC) and LCC, GIS is used to understand the spatial and temporal patterns. Remote sensing (RS) is used in acquisition of information without physical contact of the source. Up-to-date global land cover data sets are necessary for various global change research studies, including climate change, biodiversity conservation, ecosystem assessment and environmental modelling (Giri et al., 2005). Since land cover is the actual distribution of physical and biological features of the land surface, up-to-date information on the status of the land surface is crucial for environmental planning and management (Melesse, 2004).

Remotely sensed image data are widely used in terrestrial, oceanographic, and atmospheric applications such as land cover mapping, environmental modeling and monitoring as well as updating of geographical databases of the specific area (Tso and Mather, 2001). Besides these, GIS and RS provide knowledge about the geographic distribution of land cover patches, which are important characteristics for evaluating the processes and effects of changes on the landscape and the watershed level.

In general, Tatem et al. (2003) noted that accurate information on land cover is required for both scientific research (e.g. vegetation change modelling, climate change modelling, and flood prediction) and for undertaking management interventions (e.g. habitat management, city planning, disaster mitigation etc). The assessment of the land cover type existing due to socioeconomic and ecological factors helps to qualify and quantify its status and has environmental implications on the ecological requirements of species. Particularly for Simien Mountain National Park (SMNP), it is necessary to know which kind of land cover type to know the threats or opportunities to the wildlife habitat, so that further decision making processes can be initiated, and to undertake management intervention for biodiversity conservation.

Disparate national and regional methods of statistics provide no definite data on where and when land cover changes occur. Furthermore, there is no universally accepted way to measure fragmentation and to assess the complex effects of the landscape pattern on ecosystems. Documentation of spatially referenced data on historic land cover/use practice and disturbance frequency is lacking for Ethiopia in general and the SMNP in particular. The acquisition of the corresponding information and data handling is often time consuming and requires many resources, especially in areas where there is little infrastructure, such as SMNP. Consequently, the environmental alteration is insufficiently perceived and understood by decision making bodies and the local users of natural resources in order to initiate further management interventions. Insufficient knowledge and lack of information on environmental change can lead policy makers to poorly justify and undertake unsound environmental decisions, which in turn can result in an inappropriate and unsustainable natural resources management (Viglizzo et al, 2002; Saadi and Abolfazl, 2003).

The primary criterion that distinguishes mountains, like SMNP, from other land surfaces is its significant positive relief (Ghosh, 2001) which creates different patterns of slope, aspect, complexity and heterogeneity of climate, vegetation, fauna and land use distribution patterns. The distribution pattern of land cover classes, land cover change and the ecological requirements of wildlife existing in the SMNP differ with respect to altitude, slope and aspect (Menale Wondie, 2007).

Despite all the ongoing effort, information gap still exists in the understanding of the spatial distribution of LC with respect to monitoring the dynamic changes of resources. Updated information on the status of the resources is required for sustainable management, especially biodiversity conservation and management. Therefore, this paper fills the information gap of LC across different environmental parameters (altitude, aspect and slope). It can further be used as a basis of information for a further identification of different wildlife habitats and future studies of biodiversity conservation and management. The main objective of this paper is to indicate the specific location and quantity of each land cover category in relation to environmental parameters with the help of GIS and remote sensing in the SMNP, northwestern Ethiopia.

Materials and methods

Description of the study site

Simen Mountains National Park is located in the northern edge of the Ethiopian central plateau. It is 820 km from the capital city of Ethiopia, Addis ababa. The altitude varies from 1900 to 4300m above sea level. The highest peak area of the SMNP is 4300m above sea level

The rainfall pattern is characterized by a unimodal rainfall (single rainy season), whereby the highest amount of precipitation is between June and September (Hurni and Ludi, 2000). Temperature ranges from -2^{0}C to 18^{0}C. In some cases, during the daytime there are strong and dry winds.

Due to difference in land use practice, geological event, topography and climate different soil types are found in the SMNP. Andosol is found on uncultivated land above 3000m a.s.l , whereas below 3000m and on cultivation land above 3000m a.s.l, the dominant type of soil are Phaeozem, Vertisol, Luvisol, Regosol and Leptosol (Hurni and Ludi, 2000). The grassland is dominantly covered with Andosol. The very small area, with no agricultural potential is attributed to Fluvisol. The Simen Mountain is made up of thick basalt deposited on Mesozoic sandstone and limestone, Precambrian crystalline basement, and harder rocks on the foot of the escarpment (Hurni, 1986).

The main source of income and livelihood strategy of the SMNP people is based on agriculture and livestock production (Endalkachew, 1999; Hurni and Ludi, 2000). The social status and economic background are contributing to the existence of various land cover types. In SMNP, different types of land cover are identified and categorized by the study of Hurni and Ludi (2000). These are cultivation land, grassland, bush land (shrubland), forest land and escarpment (“unusable land”). Hurni and Ludi (2000) indicate different habitats with respect to different land cover types. According to Nievergelt et al. (1998) agricultural activities and animal husbandry are the major two activities intensively undergoing in the SMNP.

Methods

Landsat ETM+ of 2003 dataset was acquired and used for image analysis to derive environmental parameters. Field observations were carried out to obtain Ground Control Points (GCPs) for georeferencing the images, to understand the features of the different LC classes, to support visual interpretation of the images and to select reference areas consisting of training areas (for supervised classification) and test areas (for accuracy assessment)). Representative samples were taken from agricultural land, grassland/pasture, forest, shrubland, settlement. In addition, Geographical Positioning System (GPS) data was used to create an independent dataset reserved for accuracy assessment. Physical description of different LC classes was carried out to be used as a reference during image analysis. The land cover categorization scheme was based on Hurni and Ludi (2000) & Amsalu et al. (2007) with some modifications (Table 1).

Table 1. Land cover classes used in classification scheme.

Cover class	Characterisation, features
Agricultural land /cultivation	Cultivated and fallow land, has a characteristic pattern, for example sharp edges between fields. Dark to grey colour in the Landsat image (4,3,2 colour composition), unless the land lies fallow. Hurni and Ludi (2000) and Amsalu et al. (2007)
Grassland/Pasture	Land under permanent pasture and grassland, grassland mixed with lobelia. Homogeneous, no pattern compared to agricultural land. Hurni and Ludi (2000)
Mixed and matured natural forest*	Natural forests and woodland with a composition of different tree species
Pure Forest*	One dominating species (*Ericaceous species*, >95% of the mix)
Shrubland*	Shrubs, bushes and young tree species, bright red on the Landsat 4,3,2 colour composite

*Based on field data, modification of the classification scheme of Hurni and Ludi (2000)

The Landsat ETM+ 2003 image was georeferenced using 69 GCPs. The 2003 ETM+ Landsat image was rectified to the UTM projection system WGS-1984-UTM-Zone37N. The total Root Mean Square (RMS) error was 0.95 pixels which is about 28 metres. The residual of individual GCPs vary from 0.16 to 1.76 pixels (4.8 to 52.8 m) . Due to the rugged topographic nature of the area and the existence of limited information on GCPs for SMNP, the RMS error is assumed to be satisfactory. The orthorectification resampling method used was the nearest neighbour which is better for land cover classification (Edward (ed.), 2000; McCloy, 2006).

The method used to classify the Landsat image to the respective LC was maximum likelihood supervised classification using ERDAS Imagine 9.1 software. Pixels were clustered into the categories of five known classes: agriculture mixed natural forest, pure forest (dominant by >95% *Ericaceous species*), shrubland mixed and/or young species of trees, grassland and one unknown category that remained as unclassified (or defined as shadow). In total six categories were identified. Areas of Interests (AOIs) were selected as training areas for classification. The training points are distributed in the area of each LC type. The number of sample AOIs for agriculture, natural mixed forest, pure forest, shrubland, grassland and shadow was 128, 50, 53, 65, 56 and 34, respectively. The overall approach of land cover mapping is shown in Figure 1 below

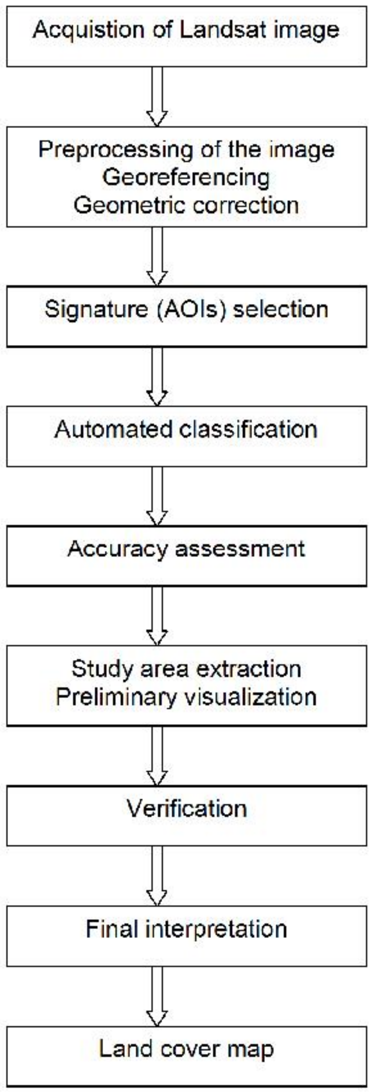

Figure 1: The approach adopted for LC mapping

Spatial analysis of LC types was undertaken to identify their distribution across the environmental parameters. Altitude, slope and aspect are categorized into five, six and eight classes, respectively. The distribution of each categories of LC is correlated to each class of environmental parameters.

Results and discussion

Land cover distribution across environmental parameters

The distribution pattern of land cover classes and the ecological requirements of both animals and plants differed with respect to different environmental situations such as altitude, slope and aspect. These three environmental parameters are considered to evaluate the distribution of different categories in the study site. Environmental parameters could sometimes be special species habitats and indicators of richness in biological diversity.

Altitude

Altitude is one of the parameters determining the distribution of land cover classes. The natural distribution of forests is sensitive to altitude due to the physiological requirement. These ranges are identified using an ERDAS^{TM} Imagine modeler. The altitudinal ranges are categorized into five classes with an interval of 500m. The categories are: below 2000m, 2000-2500m, 2500-3000m, 3000-3500m, 3500-4000m and 400-4500m a.s.l. The extent of each altitude category is indicated in Table 2 below.

Table 2. Extent of each altitude range across the study site.

	Total area in each altitude	
Altitude (meters a.s.l.)	ha	%
below 2000	225.00	1.62
2000-2500	2043.00	14.69
2500-3000	3449.34	24.80
3000-3500	4543.56	32.67
3500-4000	3590.10	25.81
4000-4500	56.34	0.41
Total	13907.34	100.00

About 98% of the study area lies between 2000 and 4000m. Only 2% are classified as lowland areas in the SMNP. The elevation category 3000-3500m is dominant (32.67%). In this elevation category 3000-3500m, 40.56% of the area is utilized for agriculture. 47% of the pure forest dominated by *Ericaceous species* is found in this range. About 55.92% of the grassland is concentrated between 4000-4500m. Land cover distribution across each slope category is indicated in Table 3 below.

Mixed forest and shrubland areas are concentrating between 2500 and 3500m. Pure forest dominated by *Ericaceous species* is a highland species, which are found mainly from 3000 to 3500m. The result shows that the increase of forest area proportionally with elevation that is higher forest was found at “Gich” plateau. The distribution of LC categories showed that the higher altitudes (between 3500 and 4000m a.s.l) are dominated by grassland and agricultural land. Agriculture and grassland has lower extent in the lower areas of the park as compared to the other LC classes.

Table 3. Distribution of LC over altitude.

Altitude (m)	Categories (ha)						
	Shadow	Mixed forest	Pure forest	Shrubland	Grassland	Agriculture	Total
Below 2000	4.23	45.45	3.42	69.57	30.96	71.37	225
2000-2500	80.91	697.86	109.17	603	190.17	361.89	2043
2500-3000	349.92	1003.86	551.88	772.83	217.17	559.98	3455.64
3000-3500	423.45	318.69	1014.12	559.8	378.27	1842.93	4537.26
3500-4000	129.51	94.59	492.93	303.75	2007.45	561.87	3590.1
4000-4500	0.09	0.09	1.62	1.08	52.38	1.08	56.34
Total	988.11	2160.54	2173.14	2310.03	2876.4	3399.12	13907.34

Aspect

Aspect is one of the environmental parameters which influence parameters such as exposure to sunlight, drying winds and evapotranspiration. Hence, aspect has implication to physiological and ecological requirement of the species. In this particular study, the aspect map of the SMNP is produced to illustrate the relationship between land cover distribution and aspect. Aspect regions are classified into eight groups (see figure 2 below) namely: north (337.5°–22.5°), northeast (22.5°–67.5°), east (67.5°–112.5°), southeast (112.5°–157.5°), south (157.5°–202.5°), southwest (202.5°–247.5°), west (247.5°–292.5°) and northwest (292.5°–337.5°). The difference between neighboring categories is 45°.

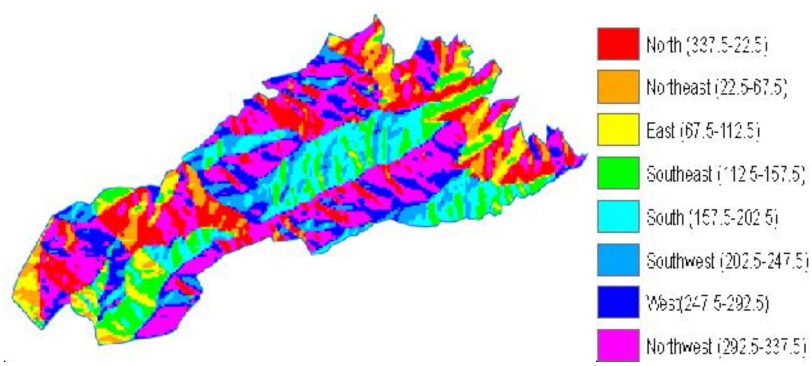

Figure 3. Distribution of the aspect categories in the SMNP

The spatial distribution of individual LC types across aspect is indicated in Table 4. As the result indicates, northwest and north directions favour the distribution of forest areas, but agriculture and grassland dominate between 112.5° to 247.5° which is southeast to southwest. Little or no flat land is found in the SMNP.

Table 4. Spatial distribution of individual cover categories across aspect.

		Categories (ha)						
Aspect	Azimuth (degree)	Shadow	Mixed Forest	Pure Forest	Shrub-land	Grass-land	Agri-culture	Row total
North	337.5 - 22.5	227.52	621.45	548.82	424.44	176.31	316.35	2314.89
Northeast	22.5 - 67.5	25.47	185.04	160.02	360.45	128.79	223.56	1083.33
East	67.5 - 112.5	8.46	65.97	53.64	311.76	146.88	317.79	904.5
Southeast	112.5 - 157.5	3.87	42.3	73.53	287.73	506.43	590.04	1503.9
South	157.5 - 202.5	3.96	35.91	127.26	193.77	723.78	549.36	1634.04
Southwest	202.5 - 247.5	32.49	136.44	101.7	165.15	426.69	401.58	1264.05
West	247.5 - 292.5	214.47	307.26	274.86	200.7	386.73	428.67	1812.69
Northwest	292.5 - 337.5	471.87	766.17	833.31	366.03	380.79	571.77	3389.94
	Column total	988.11	2160.54	2173.14	2310.03	2876.4	3399.12	13907.34

Slope

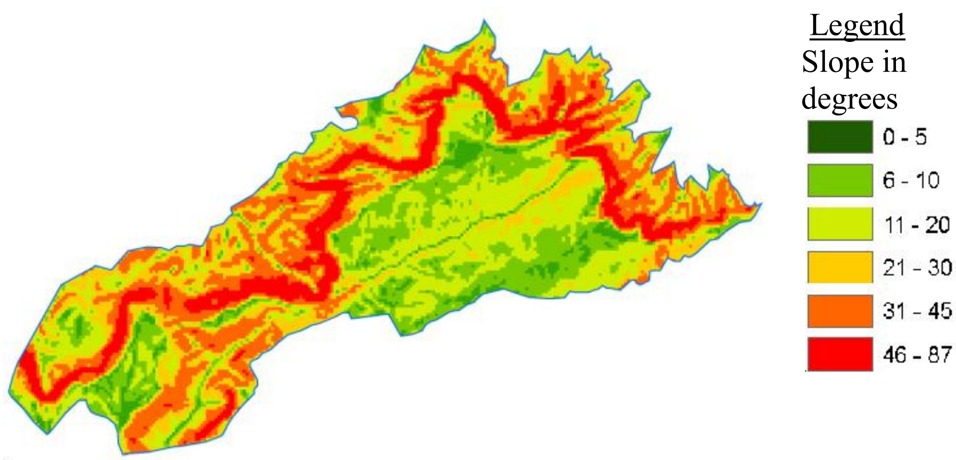

Figure 3. Categories of Slope in the SMNP

The slope map of the SMNP is categorized into six classes (Figure 3). In most of the cases the slope angle is directly related to land cover distribution and to the stability of plants. Theoretically, steeper topographic features are assumed to be not suitable to agricultural crops production and grazing land due to inaccessibility and fragility of the land.

The slopes are classified using the modeler of ERDAS. Table 5 showed the distribution each slope category According to the result slopes of 11-20 degrees are the dominating classes, but the extent of flat land is very small. 1420.92ha (65.77%) of the area of mixed forest, 1206.54 ha (55.52%) of the area of pure forest and 1241.55ha (53.75%) of the area of shrubland / young trees are situated on slopes of 21-45°. Relatively gentle slopes of 0 to 20° are covered by agricultural and grassland to the extent of 1941.93ha (67.511%) and 2177.37 (64.06%) respectively.

Table 5. Summary of area extent and percentage of each slope category

	Area coverage	
Slope category (degree)	ha	%
0-5	436.32	3.14
6-10	2298.96	16.53
11-20	3849.75	27.68
21-30	2707.83	19.47
31-45	3090.60	22.22
46-87	1523.88	10.96
Total	13907.34	100.00

Table 6. Spatial distribution of cover categories across slope

	Categories (ha)						
Slope (degree)	Shadow	Mixed Forest	Pure Forest	Shrubland	Grassland	Agriculture	Row total
0-5	1.89	11.25	8.91	25.56	233.64	155.07	436.32
6-10	10.98	70.74	76.41	156.6	1031.04	953.19	2298.96
11-20	43.11	454.05	557.82	659.7	910.89	1224.18	3849.75
21-30	90.45	696.42	525.42	644.58	254.43	496.53	2707.83
31-45	321.03	724.50	681.12	596.97	348.66	418.32	3090.6
46-87	520.65	203.58	323.46	226.62	97.74	151.83	1523.88
Column total	988.11	2160.54	2173.14	2310.03	2876.4	3399.12	13907.34

Major anthropogenic activities both agricultural activities and grazing land (grassland) are dominantly undertaken on the gentle slopes. Steeper slopes favour the survival of forests. According to table 6, the shadow increases from flat to steeper terrain. But the other LC categories have more or less a bell-shaped distribution along each slope category.

Discussion

Environmental parameters such as altitude, slope and aspect have been investigated and located. The DEM had artifacts. The artifacts became visible especially when displaying the slope, as slope patterns which never exist in nature occur in areas which obviously had been treated by the hole-filling algorithm in the CGIAR-CSI DEM. Areas of the DEM which showed artifacts were replaced by data interpolated from contour lines (isolines) of the map of Hurni (2003).

About 98% of the study area lies between 2000 and 4000m. Only 2% are classified as lowland areas in the SMNP. The elevation category 3000-3500m is dominant (32.67%) of the total area of the park. Since large areas of the SMNP are situated between 3000-4000 m a.s.l, the significant change is also observed in these altitudinal ranges. But the transformation of mixed forest and agriculture to shrubland is facilitated between the ranges of 2000 m and 3000m. Pure forest which is dominated by *Ericaceous species* increased in areas mainly at elevations from 2000 m to 3000 m. This could be due to decline of agriculture and grassland.

The slope map of the SMNP is categorized into six classes based on Hurni (1986) classification and using knowledge of the distribution of different land cover types. In most of the cases the slope angle is directly related to land cover distribution and to the stability of plants. Theoretically, steeper topographic features are assumed to be not suitable to agricultural crops production and grazing land for domestic animals due to inaccessibility and fragility of the land. But in the SMNP there are steep slopes used for cultivation of crops and used for animals grazing due to scarcity of land per household head. As indicated from the result of the study major anthropogenic activities (agriculture and grazing) are dominantly undertaken on the gentle slopes. However, steeper slopes favour the survival of the natural forests. The dominant LCC occurs at slopes between 11 and 45° slope. The conversion of mixed forest to pure forest and shrubland is higher in the steep slopes, mainly at 21 to 45°. The steep slopes were found to disfavour the expansion of agricultural and grasslands.

Aspect is one of the environmental parameters which influence exposure to sunlight, drying winds and evapotranspiration. In this particular study, the aspect map of the SMNP is produced to illustrate the relationship between land cover distribution and aspect.

The ecograms of the species can be developed by analyzing the altitude, aspect, slope and other environmental parameters and hence ecological management intervention can thus be facilitated. Wildlife habitat management and planning can be carried out in relation to environmental parameters and depending on the resource (land cover type) existed in the area. Different management activities of the major wildlife habitat conservation sites can be designed using the information of the location of altitude, aspect and slope in the SMNP.

Conclusion and recommendation

Using Landsat TM 1984 and ETM+ 2003 datasets, LC can be detected and categorized. The results of this study show that integration of GIS and remote sensing is effective in monitoring the overall status and analyzing land cover patterns as a function of environmental parameters such as altitude, slope and aspect. In general, the spatial distribution of the individual LC classes is the result of both human and biophysical nature of the SMNP.

Forests usually found on high and steep terrain where agriculture is scarce on steep terrain. The Landsat images proved notably useful in analysis of the ecological trends on a time-series basis and can be used for planning measures for restoration of the SMNP ecosystem. Detection of different environmental parameters might also help to know, plan and create a diversity of habitats available to plant and animal species, and finally contributes to overall increase of the species diversity. To meet the objectives of the SMNP, wildlife habitats, conservation sites, and management units can be identified and delineated with the help of GIS and RS to set up development strategies, design management activities and make decision on natural resources management.

Spatial analysis of LC indicates the overall situation and highlights the trends of the SMNP in terms of land cover. Therefore, this study can provide basic information for efficient and effective monitoring of land cover in relation to wild life habitat condition.

The resource managers can superimpose the land cover map to existing management and conservation zone maps and use it as a planning tool for the optimization of protection sites within the park, providing information on the status of wildlife and natural resources. Furthermore, the land cover map can provide information as an indicator of the overall environmental quality and direction of change of the SMNP. Environmental parameters may be used as hints to plan the restoration of the park and to support strategic decisions for conservation and development policy.

The ecograms of the species can be developed by analyzing the altitude, aspect, slope and other environmental parameters and hence ecological management intervention can thus be facilitated. Wildlife habitat management and planning can be carried out in relation to environmental parameters and depending on the resource (land cover type) existed in the area.
Land cover map analysis is used to display the overall situation, visualize and identify dominant LC categories, physical processes and trends in SMNP. Land cover map can be used to visualize the status of the SMNP both by indigenous people and policy makers, so that to feel the changes and suggest the possible solution.

Land use activities cannot be explained by image analysis in this study. Only the physical features of the park are displayed and analyzed. Therefore, deep investigations on the inherent characteristics of different LC classes have to be carried out. The carrying capacity of the park determines the prospective of the SMNP to conserve the biodiversity and to meet the social, ecological and economical needs of the indigenous people. To overcome this problem, it is necessary to investigate the interrelations of the environmental parameters, the land cover status, and the demand of the people. On this basis, it should also be possible to recommend an optimum size of the park to maintain the current biodiversity (mainly endemic and rare species in their specific habitats). A compromise between the stakeholders is needed to facilitate both policy issues and management strategies in relation to land cover. Management activities can be designed using the information of the location of altitude, aspect and slope in the SMNP.

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