

OBJECT-BASED CLASSIFICATION OF LANDSCAPE INTO LAND MANAGEMENT UNITS (LMUs)

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ABSTRACT:

A cost effective, reproducible and reliable system of classification of landscapes into homogeneous units characterizing land based on its physical, biological and cultural characteristics -denoted as Land Management Units (LMUs) is of significant importance for management and planning purposes. Especially for developing countries, LMU systems are very critical as they aid in decision making process for achieving sustainable development and conservation of resources.

Management and planning act requires understanding of common and distinctive properties of sites, capability of land to produce resources and respond to management decisions, hence it is essential to reduce enormous amount of environmental variability into conceptual units that reveal capacity and capability of land.

This study aims to develop a method of Geographic Object-Based Image Analysis (GEOBIA) to generate LMUs at a biodiverse region dominated by forests, shrublands and endemic species which is subject to degradation and requires natural conservancy in Blacksea region in Turkey.

Starting point for classifying landscape into LMUs is to explore landscape as groups of biotic and abiotic factors representing ecological units that have discernible structure, function, geo-morphology and disturbance regimes. Topography as a controlling mechanism and almost stable structure plays predominant role in determining ecological conditions and it addresses the question of how to best define landform based landscape entities. The proposed system employs object-based analysis of Digital Terrain Models (DTMs) to derive landform elements and utilizes landform-landcover assemblages to perform ecological regioning. Those conceptual objects that form a framework of connected entities are then enriched given other available information e.g. land use, ownership and hazards to ultimately end up with map units called LMUs.

1. INTRODUCTION

Information on land potentials and actual condition is the most crucial information that is required for environmental research and regional planning. However, there is considerable amount of variability of resources characterizing land which necessitates regionalizing of similar pieces of land into units. These units that have ecologically sound boundaries and reflecting the spatial organization of natural features (Burnett and Blaschke, 2003) are also expected to respond similar treatment in a similar fashion.

A group of biotic and abiotic factors pose distinguishable structure and function within the continuum of land such as geomorphology, surface hydrology, microclimate, vegetation and disturbance regimes (Forman and Gordon, 1986). Central to this epistemology is the problem of properly distinguishing landscape units which relies on the assumption that individual units of common biophysical characteristics reflect biotic and abiotic conditions that are relatively homogeneous within and distinct between adjacent regions (McMahon et al., 2004). In this context, vegetation, soil and landform together form main descriptors that characterize a landscape. Soil and topography are very closely related that they construct the formal basis of soil-landscape

modelling studies. Water and sediment redistribution processes are controlled by topography which largely impact pedogenesis (Wilson and Gallant, 2000), and soil and topography together control processes influencing distribution and abundance of vegetation.

Topography as a controlling and almost stable structure synthesizes many of the other factors that describe land. Differences in biotic and abiotic conditions are largely controlled by changes in topography that produce gradients in moisture, energy and nutrient flow across the landscape (Moore et al., 1993).

From ecological perspective, topography is an indirect factor, which does not necessarily have a physiological influence on vegetation or abiotic components, in contrast to direct factors such as temperature and soil nutrients (Austin and Smith, 1989). While the use of direct factors such as soil and climate data is preferable for understanding ecological conditions, data is usually unavailable or has poor relevance in terms of scale and content. We are therefore motivated to explore the applicability of delineating land units based on DTMs. DTMs can substitute environmental factors critical in landscape and ecologic studies.

Rapid growth in digital data sources suggests that data acquisition is less of a limitation than in the past.

Importance of regionalization of landscape into meaningful units has long been recognised, however for repeatability, transferability and further systematic research it is quite important to perform quantitative methods. Variety of quantitative methods has been developed that adopt multi-variate analysis to classify landscapes. DTMs that represent abiotic parameters such as soil moisture, nutrients, solar radiation are utilized (e.g. Chaplot and Walter, 2003; Zhou *et al.*, 2003). However, those attempts yield statistical conceptual units that usually lack correspondence with entities that can be labelled in line with meaningful land features.

This study proposes a regioning method based on landform units that carry concise information on land potentials that aid in further delineation into LMUs. Method is applied on a site with rough topography and vegetation dominated by forests and shrublands. It exhibits a wide range of possible combinations of landform, soil and vegetation assemblages. Object-based analysis approach is adopted to represent land as homogeneous land objects rather than individual pixels which lack coherence in geographical space with scattering of classes due to authentic overlap between classes in both attribute and geographical space. Those objects are then aggregated through higher level segmentation and reclassified according to having common landform and vegetation. This constructs landform-vegetation assemblages that portray ecological boundaries at a multilevel hierarchy of objects. Finally other available information for the study area are transferred into landform-landcover assemblages to enrich those land units to end up with Land Management Units (LMUs) that aid in decision making process.

2. STUDY AREA

The study area is located in northeastern Turkey within Yusufeli district. It covers an area of about 33000 ha and it is a subunit within Kaçkar Mountains Sustainable Forest Use and Biodiversity project area (Figure 1). The area is characteristic of the Northeast Turkey mountainous region with high relief where elevation ranges from 700-3300m with a mean slope of 23°. Area has high relief, dissected valleys with steep hillslopes and sharp crests dominating the landscape where the geomorphology of the landscape can be dated to young stage.

The region is remarkable with its natural old-growth forests, high plant diversity with many endemics, outstanding wildlife such as bears, wild goat, chamois, lynx, wolves, and perhaps leopards and mountainous landscape. Study area is situated within one of the 25 biodiversity hotspots of the world; Caucasus Hotspot (Myers *et al.* 2000). Area also keeps the bulk of priority conservation areas identified through Lesser Caucasus Gap Analysis, 7 squares out of 21 (Zeydanlı *et al.* 2006). Vegetation of the area varies from alpine grasslands to needle-leaved mixed forests, oak-hornbeam shrublands and Mediterranean type maquis formations. The area includes 202 butterfly species, 101 endemic plant species, 118 breeding bird species, 25 herpetofauna species, 11 large mammal species. However, the region is currently facing threats that would cause irreversible changes to the forest ecosystem. These major threats are uncontrolled tourism unlawful hunting and ineffective protection illegal logging and HES schemes.

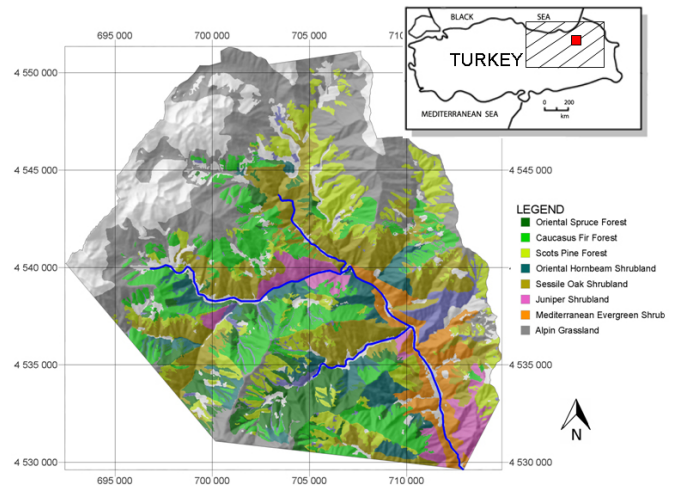


Figure 1. Study Area and its location. Main landcover types draped over the relief map.

3. METHOD

DTMs including slope, curvature, TPI (Topographic Position Index) and aspect that has strong control over environmental conditions through complex interactions are used to derive landform elements that form the basis of LMUs at landscape scale. A bottom-up approach that utilizes raw DTMs and vegetation data through enriched LMUs with a series of Geographic Object-Based Image Analysis (GEOBIA) is adopted (Figure 1).

Fundamental DTMs: 'slope', 'curvature' and 'TPI' that represent relative position of terrain are used as input for segmentation of the land into homogeneous 'landform objects'. Class boundaries of 'land cover' data is utilized as thematic input so that boundaries from landcover dataset are successfully transferred into objects layer through segmentation. 'Landform objects' rather than individual pixels are used as basis for further analysis and classification as they better conform to land features and have the ability to connect via multi-level hierarchy. Slope, curvature and TPI are utilized to classify objects into 'landforms' and then aspect (slope azimuth) is used for classification of these landforms so as to produce landform facets portraying north facing or south facing slopes that produce diverse environmental conditions. On the other side, landcover information is transferred into objects, so that each object has landform and landcover type information. These two major information are brought together to produce a higher level segmentation that aggregate objects of common landform and landcover boundaries into single objects. These coarser objects are then reclassified to obtain landform-landcover assemblages that better represent ecological conditions within their boundaries. These landform-landcover assemblage polygons form the boundary conditions for LMUs.

Assemblage classes that contain both landform and landcover information are then enriched with all other available data significant in management purposes, such as soil, parent material, natural hazards and land use, ownership and other socio-economic and cultural data.

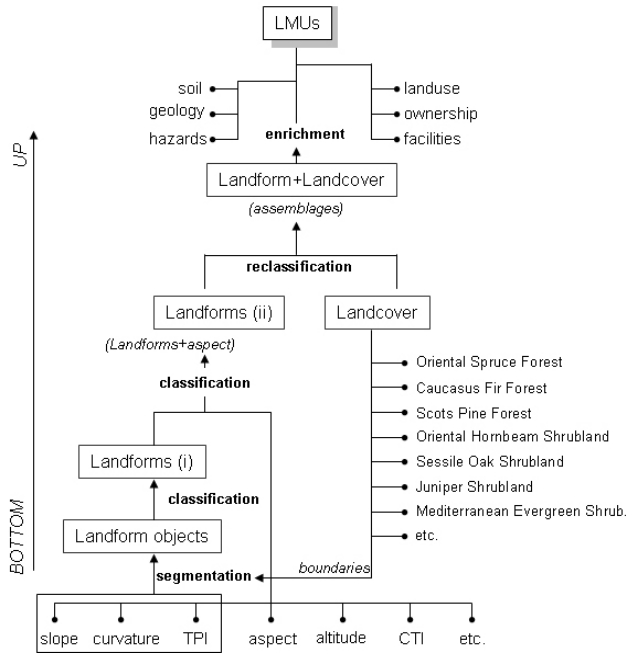


Figure 2. Flowchart of the method

Method adopts a bottom-up approach, from pixels to enriched LMUs. So that selecting a LMU object, one can reach its landcover type, landform in either microform level (Landform(i) in Figure 2) or form facet level (Landform(ii) in Figure 2) including aspect information. Other low level information like mean slope, mean altitude of the individual objects can also be reached through flexible environment of multi-level segmentation.

3.1 Landforms

Most of the studies have exercised the degree of relevance of indirect factors to environmental conditions, e.g. predictive modeling of the potential natural vegetation through a set of multivariate interval data in continuous form, e.g. altitude, Compound Topographic Index (CTI), solar radiation, etc. However, it is certainly expected that landforms have significant influence in producing particular environmental conditions. ‘Shoulders’ and ‘footslopes’ are ecologically sensitive landforms (Reuter et al., 2006) basically due to gradual change in erosion regime, exposure, soil thickness and moisture. For instance, in downslope sequence across a hillslope there is systematic change of sediment where sediment accretes on footslope positions which produce cumelic soils (Ruhe, 1975) and matter is eroded from higher positions so that there is less soil thickness in crests and shoulders compared to lower positions producing limitations in plant growth. Convergent and divergent slopes are described by curvature and they produce different environmental conditions such that a convergent slope is moister and have more accumulated material where a divergent slope is more exposed to sun and wind and is less moist. Aspect is also critical as north facing slopes are more moist and cooler compared to south facing slopes that receives more solar radiation. Due to suitability of moisture conditions, vegetation cover is more abundant on north

facing slopes which also results in higher soil thickness and the situation is opposite in the south facing slopes.

Landform model of Pennock (1987) which exhaustively covers topography as landform classes significant for ecological processes is adopted for this study. Pennock et al. (1987) classified nine three-dimensional sloping elements by measures of slope, plan and profile curvature and two leveling classes namely; crest and channel. Landforms are described with rate of change of slope in both vertical and horizontal plane. This scheme is also compatible with the scheme of Ruhe (1975) and Dikau (1989) that represent form only, and more over Pennock’s scheme (1987) represent terrain position information which makes it suitable for use in ecological classification studies (MacMillan and Pettapiece (2000). These forms are further reorganized so as to represent more simplified Landforms (2nd column Table 1) and aspect information is further involved that is critical for energy, i.e.; heat and light (3rd column Table 1).

Landforms of Pennock (1987)	Landforms	Landform+ aspect
Crest	Crest	Crest
Divergent Shoul. Planar Shoul. Convergent Shoul.	Shoulder	Shoulder North Shoulder Shoulder South
Divergent Backsl. Planar Backsl. Convergent Backsl.	Divergent Backsl. Planar Backsl. Convergent Backsl.	Backsl. North Backsl. Backsl. South
Divergent Footslope Planar Footslope Convergent Footsl.	Footslope	Footslope
Channel	Channel	Channel
11 classes	7 classes	9 classes

Table 1. Landform classes

DEM at resolution of 25m generated out of 1/25000 topographic contours with topogrid of ArcGIS (an implementation of AnuDEM that produces hydrologically correct DEMs) constitutes the basis of all DTMs used in this study. Slope and curvature is calculated using Landserf at window size of 25x25 so as to represent surface at landscape scale. Original data values were used for segmentation, however for classification, DTMs were normalized into 0-1 ranges to verify that the classification will work with same thresholds at other case areas as well. Cosine of aspect (CosA) was used instead of raw aspect values to represent slope azimuth as north facing or south facing.

3.1.1 Segmentation: Slope, curvature (plan, profile, maximum and minimum curvature) that describe form (Dikau, 1989) and TPI that describe the relative position across the landscape were used as input into segmentation process. Fractal-based multi-scale segmentation algorithm developed by (Baatz and Schape, 2000) provided in commercial object-based image analysis system: eCognition is utilized in segmentation of land into small homogeneous ‘landform objects’.

3.1.2 Classification: Classification for the study mainly comprises of two parts; initially; objects gathered out of segmentation are classified based on local geometry and position, slope and curvature determine the local form and TPI determines the position in downslope sequence; e.g. ‘shoulder’ is a hillslope

form so it is a sloping feature, it has convex profile curvature and it is located at relatively higher positions across the landscape characterized by high TPI values. Semantic Import (SI) model is adopted to classify objects based on normalized slope, curvature and TPI values (Gerçek, 2010). Seven landform classes of Pennock (1987) that depict ecologically critical landform classes were derived as shown in 2nd column in Table 1.

Another classification that is based on form facet model (Dikau, 1989) is implemented to end up with landform facets or landform+aspect classes. Sloping landforms; shoulders and backslopes were subdivided as north facing, south facing and other as shown in 3rd column in Table 1. Foothills were excluded as they have low slopes with undefined aspect.

3.2 Landcover

Landcover data for the study area is produced based on image interpretation, field survey and older forest maps within the Kackar Mountains Sustainable Forest Use and Biodiversity Project.

Classification system is based on the physiognomy of the vegetation in the first level and floristic features according to dominant species and associated species in the second level (Jennings 1999). Final map has hierarchical structure that can be used in different scales and for different management purposes such as habitat suitability modelling, protected area zoning, forestry applications. Final map bears five physiognomic class twelve physiognomic subclass and 113 alliances. However, for this study 113 alliance types were combined to 7 major landcover types due to practicality of analysis as high number of alliances may create noise in interpretation of the results. Major landcover types obtained through combination of alliances are as follows; Oriental Spruce (*Picea orientalis* L.) Forest, Caucasus Fir (*Abies nordmanniana* Mattf) Forest, Scots Pine (*Pinus sylvestris* L.) Forest, Oriental Hornbeam (*Carpinus orientalis* Mill.) Shrubland, Sessile Oak (*Quercus petraea* (Mattuschka) Lieb) Shrubland Juniper Shrubland (*Juniperus* sp.), Mediterranean evergreen shrubland and Alpine grassland.

Landcover is a vector polygon layer and it is utilized in segmentation process as boundary condition. Therefore, initial landform objects besides having boundaries that determine homogeneous landform units, involve boundaries introduced by landcover types. This spatial information further provides easy transfer of landcover types into objects as each object carry boundary conditions belonging to landforms and landcover. Otherwise, a vegetation type would most probably partially coincide with a landform object and one should have to transfer only major landcover type coinciding with the object or create a proportion of different types that fall into a single object.

3.3 Landform-Landcover assemblages

Discriminative power of landform as a dominant control mechanism on biotic and abiotic factors that moderate ecological conditions can be combined together with its closely related component ‘vegetation’ to construct landform-landcover assemblages. Vegetation is strongly related with environmental conditions and it is assumed that undisturbed vegetation or potential vegetation is descriptor of the ecological conditions at

that particular space crowded by that vegetation (Bailey 1996, Omernick 1987). Although vegetation in the area is under influence by human for very long periods and it can not be claimed as merely potential, it still has significant relevance to the conditions that provide its particular abundance. Major landcover types and their relation to landforms are examined through chi-square test and the results portrayed significant correlation.

Landforms with aspect information (3rd column of Table 1) have shown stronger relationship to major landcover types (Table 2) therefore they are selected to be used as landform classes in further analysis

Landcover type	chi-square for landforms	chi-square for landforms (+aspect)
Oriental Spruce Forest	28.34921	140.2911
Caucasus Fir Forest	114.6288	273.9556
Scots Pine Forest	74.74214	195.352
Oriental Hornbeam Shrubland	31.48607	37.0501
Sessile Oak Shrubland	174.9733	260.0567
Juniper Shrubland	22.43	25.52
Mediterranean Evergreen Shrubland	302.7082	306.8828
Alpine Grassland	133.5296	139.0828
Test statistic	critical value for P = 0.001 at d.f.=6 is 22.46	critical value for P = 0.001 at d.f.=8 is 26.13

Table 2. Chi-square test for Landforms vs. landcover

Subsequent procedure focuses on the segmentation and classification of landform and landcover into meaningful assemblages. This higher level segmentation is aimed at deriving coarser units of landscape out of objects that are common in both landform and landcover. As a consequence number of objects is reduced and they become larger without any loss of information. Moreover initial objects and associated information can still be reached if needed through multi-level hierarchy of object levels. Higher level landform-landcover objects are then classified into Landform-Landcover assemblages producing possible combinations of landform and landcover like for instance; ‘ShoulderNorth-Oriental Spruce Forest’ that represent north facing shoulder slopes vegetated with Oriental Spruce.

3.4 Land Management Units (LMUs)

Final step is the enrichment of landform-landcover assemblages with other spatial information available for site. Soil, parent material, hazards, land use types, endangered species, ownership etc. is assigned to each object of common landform-landcover.

Landform-landcover assemblages carry useful information on potentials of land and describe ecological conditions. Added further information brings a multilayered information content that can be efficiently utilized for management purposes. Each LMU besides its own physical properties is carrier of other valuable thematic information.

4. RESULTS AND DISCUSSION

Method produces LMUs that portrays common biotic and abiotic factors that moderate ecological conditions and carry important information on land. A bottom-up approach initially shifts analysis environment from individual pixels to the object domain. Figure 3 a and b is the segmentation result for a small sample area within the region. A medium scale segmentation is applied that is not very low to produce oversegmented scene or high to produce objects that involve divergent properties.

Each object represent ecologically significant form, position and orientation information that produces gradients in moisture, energy and nutrients; i.e. landforms (Figure 3 a). Segmentation process transfers boundaries of landcover types to objects which is critical for adequate representation of landcover types. Landcover attributes transferred successfully without loss of information into objects (Figure 3 b). Finally both landform and landcover information are brought together through a higher level segmentation of objects into coarser landform-landcover assemblage objects that portray ecological conditions (Figure 3 c).

Eight landforms when combined with eight landcover types produce 64 possible combinations of landform and landcover. However, there are 58 actual combinations in the study area where about one third of them are very small in areal extents that they could be ignored regarding a smallest mapping unit criteria as a scale indicator. Landforms and landcover types in the area show significant correlation. Null hypothesis that ‘the two categorical variable sets; landforms and landcover types are not related’ is rejected at $P=0.001$ at relevant degrees of freedom (Table 2). Chi-square values for landforms with aspect (Landform+aspect in 3rd column of Table 1) yield higher values compared to landforms (Landforms in 2nd column of Table 1) depicts that the relation is far more than random for these landforms, therefore they are used for four coupling landcover types to produce landform-landcover assemblages. Chi-square is calculated for each landcover type (Table 2). Accordingly; Caucasian Fir, Oriental Spruce, Alpine grassland, Mediterranean shrubland and Scots Pine distribution is strongly correlated with the landform types. As Oriental Hornbeam and Juniper shrublands has wider ecological tolerance, they do not show strong correlation with specific landforms. Juniper shrublands are even uncorrelated with test statistic lower than the critical value. Inclusion of aspect information into landform classification does not change the significance level of Alpine grasslands, Mediterranean Shrubland, Oriental Hornbeam Shrubland considerably. On the contrary significance level of Oriental Spruce increases from 28.35 to 140.29 with the inclusion of aspect to landform classification. Significance levels for Caucasian Fir, Scots Pine and Sessile Oak shrubland increases with the inclusion of aspect as well.

Moreover distribution of landforms for each landcover type is examined and compared to the general distribution of the landforms for whole study area. Simple rationing shows that some of the landcover types have particular preferences of landforms. Accordingly; Oriental Spruce and Caucasian Fir is strongly associated with north looking faces of backslopes. Oriental Spruce is even more related with north facing backslopes and it does barely exist on shoulder slopes where Caucasian Fir would exist. This is mainly due to difference in ecological preferences and tolerances of the two species.

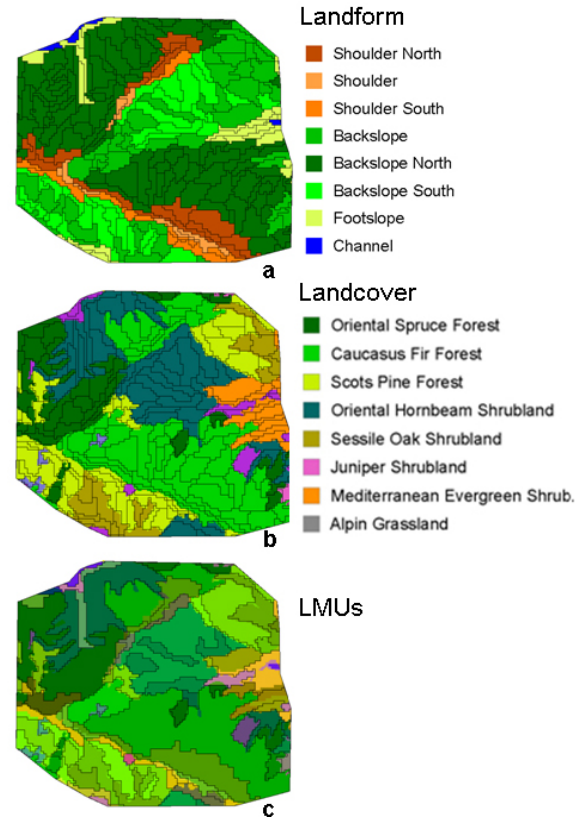


Figure 3. Segmentation and classification results for a sample area of 2500 ha within the study area a) Landform objects classified into landforms b) Landform objects classified into landcover types c) Landform-Landcover assemblages

While both species prefers more humid areas Caucasian Fir is more resistant to drought thus can tolerate even less humidity meanwhile Oriental Spruce is less resistant to drought and scarcely grows in the south faced aspects.

Scots Pine is strongly associated with backslopes and shoulders with south and east or west direction but not the north facing slopes as is attributed as light tree and prefers more sunny slopes. Species like Caucasian Fir and Oriental Spruce outcompetes Scots Pine in more humid environments. Half of the oak shrubland coverage coincides with footslopes and channels and the remaining quarter with south facing backslopes, showing that oak is strongly associated with lower positions of the landscape, preferably the south facing slopes. While it is usually replaced by oriental hornbeam on north faced slopes which outcompetes oak in more humid conditions. Oriental Hornbeam have significant relationship with landforms however with a low test statistic, hence it is not surprising that it doesn't have a particular preference of landforms across the landscape. This is mainly due to broad ecological tolerance of the species. Mediterranean Shrubland is very strongly related with channels and footslopes as expected and aspect has no relevance. Mediterranean shrubland, as its name denotes, does not belong to Blacksea region but an enclave from the tertiary age (Atalay 1994). And the only reason of existence is specific landform along Barhal Valley that creates suitable environment for the Mediterranean type shrubland formation.

5. CONCLUSIONS

Many environmental factors influence the expression and management potential of ecosystems, however topography synthesizes many of the other factors. Landforms influence, and show covariance with a variety of site factors including microclimate, soil thickness, nutrient regime, vegetation composition, hence understanding landforms and geomorphological processes is necessary to understanding the ecology of landscapes. Another point is that; landforms are the most permanent and stable feature of the ecosystem and are relatively easy to identify in the field. If the important site factors (soil characteristics, microclimate, vegetation distribution, etc.) can be correlated and understood in terms of their relationships with landforms, characterization of geomorphic properties may serve as excellent baseline information for understanding and managing landscapes. Landforms together with landcover in this study produce representative units for ecological conditions. These units may become the key for assessing habitat distribution, landscape composition or land use changes. Enrichment of those units into LMUs provides a formal background for further planning and management purposes in a multi-level network of hierarchy.

Such ecologically based LMUs are also necessary for effective communication and easy exchange of information between land resources managers. LMUs proposed reflect potential and actual condition of the pieces of land. Same class of LMUs reflect similar land potentials and are expected to respond similar decisions in a similar fashion. Further research will be focused on evaluating efficiency of proposed LMUs in management and decision making process especially on conservation for the study area. However of method is not only limited to management of forest ecosystems and conservation but also suitable for the broader land planning, agriculture, conservation management purposes.

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