INVENTORY OF ALPINE-RELEVANT PARAMETERS FOR AN ALPINE MONITORING SYSTEM USING REMOTE SENSING DATA

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ABSTRACT

The Alpine environment, one of the most sensitive of Europe's terrestrial ecosystems, is exposed to immediate and considerable environmental threat. The International Convention on the Protection of the Alps demands comprehensive counter-measures and recommends that an Alpine information system should be implemented. The goal of the project was to compile a basic landscape register for an Alpine Monitoring System (ALPMON) by means of combined analysis of high resolution satellite sensors of Alpine landscapes selected for their typical characteristics. The feasibility of the Alpine Monitoring System was tested for Alpine specific applications in close co-operation with the responsible experts so that the procedures developed can be put into practice. The Swiss National Park was supported by establishing a spatially comprehensive inventory of grass areas, forest stand characteristics and non-vegetated areas in order to set up a better basis for national park management and research. The Avalanches and Hydrogeological Defence Experimental Centre of Arabba (Italy) was interested in the improvement of its operational capability to periodically assess the erosion risk over wide alpine areas, requiring information on the actual land cover. Despite some constraints, satellite remote sensing proved to be the only suitable tool for repeatedly deriving information on the alpine vegetation taking into account the extraordinary high cost and time effort of conventional methods.

KURZFASSUNG

Die Alpen, eines der empfindlichsten Ökosysteme Europas, sind unmittelbarem und erheblichem Druck durch natürliche wie anthropogene Veränderungen ausgesetzt. Die Alpenkonvention fordert umfassende Gegenmaßnahmen und empfiehlt zu diesem Zweck den Aufbau eines Alpenbeobachtungs- und -informationssystems. Ziel des hier präsentierten Projektes war der Aufbau einer Landnutzungsdatenbank mit Fernerkundungsmethoden für einige typische alpine Landschaften als Grundlage für ein Alpenbeobachtungssystem. Die Eignung des Alpenbeobachtungssystems wurde anhand mehrerer alpenspezifischer Fragestellungen in enger Zusammenarbeit mit den betroffenen Experten getestet, um so eine Umsetzung der entwickelten Methoden in die Praxis zu ermöglichen. Der Schweizerische Nationalpark wurde beim Aufbau einer flächendeckenden Inventur von Wiesen/Weiden, Waldbestandesmerkmalen und vegetationslosen Flächen unterstützt, um eine bessere Grundlage für Nationalparkmanagement und –forschung zu schaffen. Das *Avalanches and Hydrogeological Defence Experimental Centre of Arabba* (Italien), war an einer Erweiterung seiner operationellen Möglichkeiten interessiert, Erosionsrisiken über größere alpine Bereiche periodisch zu beurteilen, und benötigt dazu Informationen über die aktuelle Landbedeckung. Abgesehen von ein paar Einschränkungen erwies sich die Satellitenfernerkundung als einziges brauchbares Werkzeug um wiederholt Information über die alpine Vegetationsbedeckung zu erhalten, vor allem unter dem Aspekt des außerordentlich hohen Kosten- und Zeitaufwandes herkömmlicher Methoden.

1 INTRODUCTION

The International Convention on the Protection of the Alps (Alpine Convention) concluded that the alpine environment is under imminent threat, and demands comprehensive counter-measures. While the Alps represent one of the most sensitive ecosystems in Europe the pressure on them is far greater than on other environments. Far-sighted national and cross-border planning is necessary to ensure that preventive measures can be implemented by nature conservation councils, regional planning departments, tourist boards and forestry and agricultural authorities. The success of such measures crucially depends on the availability of information about the kind of alpine vegetation patterns found and their development dynamics.

The goal of the ALPMON (**alp**ine **mon**itoring) project was to compile a basic landscape register for an Alpine Monitoring System by means of combined analysis of diverse satellite sensors. This system serves as the basis for planning actions. The investigation was carried out in different alpine landscapes selected for their typical characteristics. The components of the alpine monitoring system were, firstly, derived from the results of a classification of high resolution satellite images and, secondly, extrapolated from thematic maps. In order to keep the results comparable over the entire Alpine region, the information levels were harmonised in the test sites. To demonstrate the feasibility of the alpine monitoring system specific applications were performed in close co-operation with national customers in the following fields:

- Hydrological modelling of water run off
- Assessment of avalanche and landslide risks
- Development of a remote sensing aided environmental quality assessment in respect of tourism
- Supporting national park research and management
- Integration of classification results in CORINE land cover (Steinnocher et al., 2000).

In this paper the general aims of the project and the methodologies used to meet the overall objectives are described. The realisation of planning and analysis tasks in the Alpine environment are demonstrated by means of two selected applications.

2 BACKGROUND OF ALPMON

The motivation for the project was on one hand the to some extent critical state of the Alps and their sensibility to changes due to natural as well as human developments. On the other hand, in 1996 the Alpine Convention set up a working group "Monitoring of the Alps" which has defined as its main task the development of methodologies for the establishment of an "Alpine Monitoring and Information System" (ABIS). This information system should provide information – among others - on the condition of the alpine environment. Yet due to high cost and labour intensity associated with conventional investigation methods such as aerial photo interpretation and ground survey this kind of investigations was restricted to a few small areas. In comparison to conventional methods satellite remote sensing represents an ideal and highly cost efficient instrument for objective and standardised data acquisition. Further advantages are that satellite images can synoptically record wider areas, and that using these data it is possible to observe the same areas repeatedly which permits monitoring over many years. The latter is essential when dealing with a sensitive ecosystem such as the Alps.

The goal of the ALPMON project therefore was on one hand to provide cartographic information on the type, condition and distribution of the vegetation in the five test sites which can be used as information source for the ABIS-system. On the other hand it aimed at contributing to technical and conceptual aspects of ABIS by providing a concept for the establishment of a remote sensing based Alpine Information System. ALPMON thus supports two of the Alpine Conventions activity lines, i.e. collecting information on environmental indicators, and cartography. The information derived by means of remote sensing shall serve as a basis for the planning of corrective measures and their monitoring. To demonstrate the feasibility of the satellite remote sensing techniques for this purpose, different applications dealing with problems typical for the Alps were carried out in close co-operation with the national end users concerned.

3 METHODS

As the project was strongly user driven, the first task was to collect the requirements of both the national customers as well as the customers on European level. A detailed parametric description of the environmental indicators to be integrated into ABIS is established by experts of the Alpine Convention. Based on the already available parameters a nomenclature was established and harmonised for all alpine test sites to get comparable results. The parameters were mainly forestry related, comprising the forest border, forest type, natural age, and canopy closure. Additionally, general alpine land cover classes apart from forest were included. The nomenclature was organised in an hierarchical structure, thus enabling the expansion to additional respectively more detailed classes which were relevant for the specific applications.

With respect to the requirements of the end users which are expected to implement the remote sensing techniques in their information systems or models, only operational methods were applied in the project. High resolution remote sensing data of diverse satellite sensors such as Landsat 5 TM, SPOT 2/3, and IRS was acquired for the test sites.

The geometry of the images has to meet extremely strict requirements in order to enable multi-sensoral classification of images from different sensor systems and integration with other map data in a GIS. Because of the strong relief effects parametric geocoding methods were used in order to obtain the demanded sub-pixel accuracy (Almer et al., 1991). Topography does not only affect the geometric properties of an image but as well has a significant impact on the

illumination and the reflection of the scanned area. The correction of topographic effects on the spectral signal in most cases was carried out by the use of parametric approaches namely the Minnaert and the C Correction (Jensen, 1996).
Primary information on the land cover with special respect to the nature and state of vegetation was compiled solely by means of remote sensing. Detailed ground truth was collected by means of aerial photo interpretation and field surveys. This information was used for training of the classifier as well as for verification of the classification results, using independent reference data sets for each purpose. The classifications were based on common classification algorithms, such as maximum-likelihood, threshold-level procedures, and unsupervised classification algorithms, as these represent efficient, solid and, above all, operational methods for the compilation of vegetation and land cover classes. Additional information, such as altitude or geological condition, was introduced into the classification of selected parameters in order to improve their separation by class specific rules.
The results were firstly used to produce maps with respect to the European customer Alpine Convention, and secondly integrated into application specific GIS respectively models together with additional information derived from DEMs and existing maps. With these activities an advanced basis was established, thus enabling the application for planning and analyses tasks according to the customer needs. Finally, the results of the feasibility studies were evaluated by the local customers with respect to their potential for operational application. In the following, two selected applications will be presented.

4 NATIONAL PARK MANAGEMENT

The Swiss National Park, first established in 1914, is the largest protected area and the only national park of Switzerland. It is located in the high-alpine region of the Engadine and covers an area of nearly 170 km^2. The park not only serves touristic purposes, but also embodies a field laboratory for many nature scientists. A huge amount of scientific research has been achieved over the last 80 years, adding to a lot of documentation of this area. Unfortunately, no area-wide spatial data coverage is available for the whole park, since researchers are allowed to leave paths only in specified areas for which they have a permit. Thus, there is a need of a spatially comprehensive inventory of grass areas, forest stand characteristics (stand density, natural age class, tree species composition) and non-vegetated areas in order to set up a better basis for national park management and research.
Many of the above mentioned requirements are also needed by the Alpine Convention (customer on European level), of which additional classes were considered for the Swiss customer to support the research in the park. Within the boundaries of the park, habitat analysis of mountain ungulates builds the core research topic for the Swiss National Park Administration. Within the scope of habitat analysis, the monitoring of grazing areas of red deer (Cervus elaphusL.) is essential for the understanding of their seasonal movements. Ungulate-specific habitat types, classified from satellite data, are forest stands with disperse crown coverage (<10-30%) and grassland areas. Information on the distribution and type of grassland, as well as open forest shows potentially used grazing areas.

4.1 Method

For this study the feasibility of Landsat TM forest stand and grassland classifications in an alpine environment was tested against 104 reference areas. The satellite dataset is a 7-band TM mini scene (193-27/28) of 8 June, 1996. The reference data was stereoscopically delineated from infrared aerial photographs from the same year (scale 1:7000 to 1:9000) and described according to 30 parameters. All reference areas were verified during a 5-day field survey. The reference was randomly split up into independent training and verification set.
The satellite image was geocoded to the rectangular co-ordinate system of the Swiss topographic map 1:25'000. The geometric correction was done with a parametric approach using a sensor model and a digital elevation model to correct for displacements due to variations in terrain elevations. Radiometric corrections included the topographic normalisation after Minnaert.
A hierarchical approach combining supervised and non-supervised classification methods was applied on the Landsat TM data. In a first step, forest was separated from non-forest using the non-supervised non-parametric Narendra-Goldberg clustering algorithm. This is a very simple method as the number of clusters do not need to be specified a priori. In a second step, the resulting classified forest was discriminated according to different forest stand characteristics using the Maximum Likelihood method. The next step was to generate a non-forest mask with the help of the forest class. Then, the non-forest classes (grassland, water, rock, gravel, soil, sealed surface) were ML-classified. The last step consisted of analysing the classified grassland. The vegetation index NDVI was applied for the purpose of detecting differences in reflectance, which could hint at different vegetation types and structures.

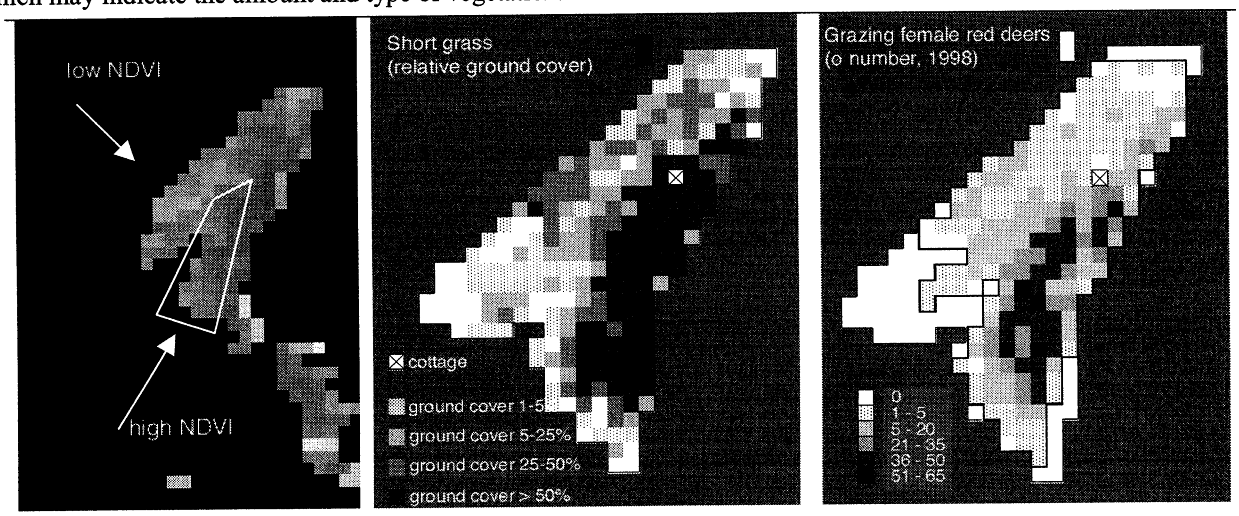
4.2 Results

Overall forest/non-forest classification accuracy yielded an impressive 95% (kappa coefficient of 0.9). This rather good verification result for a high-relief environment can be explained with the selection and spatial distribution of the reference areas. These areas are clustered samples, which lie distinctly within forest boundaries and consist of homogeneous forest stands. Not included in the reference were areas along the tree line showing open and disperse forest. Astonishingly, even the topographically uncorrected image showed a similar accuracy, when verified with the reference areas. The confusion matrices did not show significant differences. Visual verification on the basis of s/w digital orthophotos (1:21'000-1:28'000) of 1997 revealed though, that the topographically normalised image produced a better representation and classification of the forested area in the National Park.

The forest stand composition (i.e. tree species) classification did not produce satisfactory results (0.54-0.7), but visual verification on the basis of the digital vegetation map (Zoller, 1995) showed a more or less random classification result. Signature analysis indicated that that different types of conifers can not be discriminated from each other, because spectral signatures are nearly identical. For example, larch stands (Larix decidua) were better classified in the topographically uncorrected image. Visual analysis also showed that these stands could only be distinguished on directly illuminated slopes. An explanation of the unsatisfactory classification result in the topographically corrected image could be the following fact: the disadvantage of the topographical normalisation is that the data values were homogenised according to a specific object, which in this case was the forest, thus removing the larch-specific spectral signature. The topography affects the spectral differences between conifers, which can not be corrected sufficiently with the illumination correction by Minnaert. Also, insufficient spatial resolution and perhaps spectral resolution adds to the inability to detect different tree species.

Since the forest stand composition classification yielded unsatisfactory results, the classification of forest stand characteristics was reduced to three crown cover classes only. Over 95% of the alpine forest consists of conifers. Thus, the parameter crown cover was classified directly with the forest mask, even though the crown coverage is interrelated to tree species and should be considered. The accuracy assessment of the forest stand crown coverage classification gave a mediocre accuracy measure (kappa coefficient of 0.65 - 0.75). Selected reference areas were visually checked, which showed that the classified crown coverage for conifers seemed very random and hardly reliable. It has to be stated, that the crown closure of a particular stand is difficult to measure during a field survey, as the categories were artificially defined.

The classified grassland was further analysed with the vegetation index NDVI. The NDVI results (Figure 1, left) were compared to a vegetation survey taken by Achermann (2000) (Figure 1, middle) and the red deer observations by Leuzinger (2000) (Figure 1, right). Despite the lack of physically-based radiometric corrections (i.e. calibration, atmospheric corrections), the pattern of the NDVI values for the selected alpine meadow, Alp Stabelchod, showed a similar pattern as the vegetation survey. It is certain that high reflectance of vegetation yields high NDVI values. The right side of alpine meadow shows a higher reflectance than the left side, which should indicate a different composition and structure of grass species. The surveyed meadow shows that the ground coverage of the 'short grass' species correlates highly with the NDVI values. In other words, high ground coverage of 'short grass' species correlates with high NDVI values. The 'short grass', which is a term describing the vegetation structure, resembles a short kept and densely grown golf green, whereas the left side of the meadow consists of longer grass and open patches. The 'short grass' species are the preferred fodder for female red deer grazing on the meadow during the night (Figure 1, bottom right). This analysis showed that there is a significant correlation between 'short grass' vegetation and the NDVI values, which may indicate the amount and type of vegetation.



NDVI computation of Alp Stabelchod: right side containing high NDVI values

Field survey of the relative ground cover (%) of short grass (Festuca rubra, Agrostis tenuis, Briza media, Trifolium repens, Galium pumilum, Plantago media) (Achermann 2000).

Average number of observations of grazing female red deer done during 50 nights between May and September 1998 (Leuzinger 2000).

Figure 1: Comparison of terrestrial surveys with NDVI results of Landsat TM data

4.3 Conclusion

The Swiss National Park Administration has carried out visual verification of the provided forest stand crown cover and grassland classification. Results have been compared with point observations of red deer, recorded by park rangers mapping their spatial distribution in a quarterly field surveys. First results positively convinced the Swiss National Park of the use and employment of this modern technology of remote sensing data. Also, several results have been delivered as input to different mountain ungulate research projects and diploma theses, which are still in the process of being analysed.
Besides the classification results, which were of use for the Swiss National Park, advancement was achieved on the methodological level. Statistical accuracy assessment with the help of a confusion matrix and accuracy measures is widely used. Though in this project it proved not to be enough for the assessment of the classified satellite data. The classification of forested area and grassland exemplifies this. Despite the high accuracy measure of the forest/non-forest classification of over 0.9 (kappa coefficient) for both topographically normalised and uncorrected Landsat TM image, visual verification with digital orthophotos showed different classification result. Analogue to the classified forest, the category 'grassland' showed no significant difference in accuracy between the topographically corrected and uncorrected classified Landsat TM scenes, though visual verification shows clearly that the corrected scenes produced better results. Theoretically the problems of undetected fragmented forest areas near the tree line, as well as with forested areas, which are not directly illuminated are not new. The point is that the whole procedure of verifying classified satellite images with reference data is highly dependent on how this ground truth was collected. This poses the question on how ground truth should be collected, so that alpine-specific and problematical areas are also considered.

5 EROSION RISK ESTIMATION

The Avalanches and Hydrogeological Defence Experimental Centre of Arabba, located in Dolomites (Italy), is a board of the Veneto Regional Council which has in charge the preservation of the alpine environment. Soil protection is a primary commitment implying researches in the fields of solid transport, alpine meteorology, snow and avalanches. The Centre developed, in the frame of the EROSLOPE project (EV5V-0179), a system for the real time monitoring of the solid, fluid and nutrient transport, in a small pilot basin (Cordon river: 5 km^2). The system was conceived to investigate the transport phenomenology in relation to runoff and environmental parameters under well controlled conditions. All the input parameters were gathered through very accurate ground surveys. Besides this basic research experience, the Centre is interested in the improvement of its operational capability to periodically assess the erosion risk over wide alpine areas. To carry out this task in a cost-effective way the Centre wants to reduce the use of ground surveys exploiting remote sensing technologies. The purpose of this application is to develop a methodology for the assessment of erosion risk over the test site area of the upper Cordevole river basin, 265 Km^2 wide, using land cover parameters derived from satellite remote sensing and designing an erosion risk model suitable to the particular features of alpine environment: 1) extreme variability of climatic conditions with altitude and aspect; 2) peculiar morphologic features (e.g. slopes deeper than 40%); 3) different, locally dominant, geomorphic processes (e.g. debris flows, landslides, rockfalls, avalanches); 4) areas covered by snow or ice.

5.1 Method

Land cover plays an important role in the assessment of erosion risk in alpine environment because, even though it accounts for only a part of the total amount of the required information, it changes very quickly as compared to the other parameters, being the most sensitive to the human pressure. In fact morphological and geo-pedological information can be considered quite stable along time and could be acquired once a time over a reasonably long period (nearly 20-50 years), while climate information should be updated more frequently (nearly 10–20 years) and finally, land cover information should be updated very frequently (1–5 years). The review of the existing studies on soil erosion indicates that current basic methodologies have been established primarily to assess soil erosion risk over agricultural and hilly areas in temperate climate where sheet and rill erosion processes are prevailing. These methodologies therefore cannot be directly applied to a much more complex system, such as the alpine environment where many different mass erosion processes are active. Therefore, the use of a single model could hardly account for all the features of the alpine erosion phenomena. These considerations led to the design of an erosion risk model, called FSTAB (Fuzzy Stability) composed by two sub-models, DA (Discriminant Analysis) and SCS-CN (Soil Conservation Service – Curve Number). The two sub-models account for the different factors influencing mass erosion processes. The DA sub-model, specifically built for this study on statistical basis, accounts for the static factors: land cover, soil and morphology, while the SCS-CN sub-model, an already available and well known potential infiltration and runoff model, accounts for the dynamic effects of rainfalls. The output from the two sub-models are integrated in an inference engine, based on fuzzy logic, which gives a reasoned erosion risk index, called MEHI (Mass Erosion Hazard Index). The inference engine, for the assessment of the global risk, is based on a set of decision rules defined by a human expert.

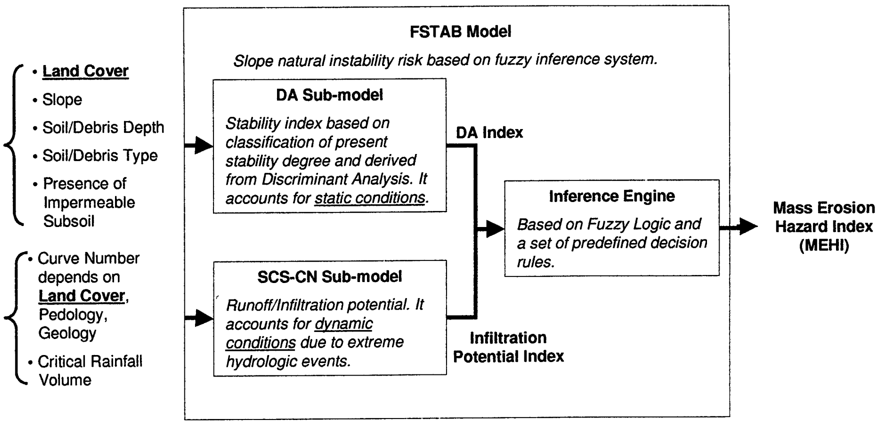


Figure 2: Overview of the erosion risk model

The following land cover classes were considered necessary as input to the model: 1) Broad-leaved Forest, 2) Mixed Forest, 3) Coniferous Forest, 4) Rhododendron/Juniperus, 5) Pasture, 6) Meadow, 7) Water, 8) Rock, 9) Sealed surfaces. Three different levels of vegetation density, i.e. 10-30%, 30-60% and more than 60%, were applied to the vegetation classes Forest and Pasture. The overall methodology is shown in Figure 3.

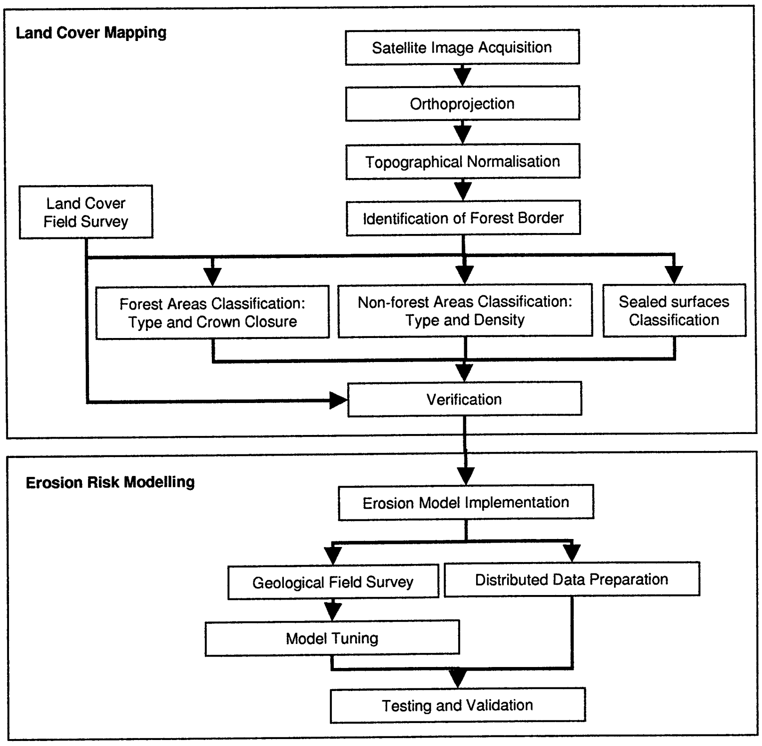
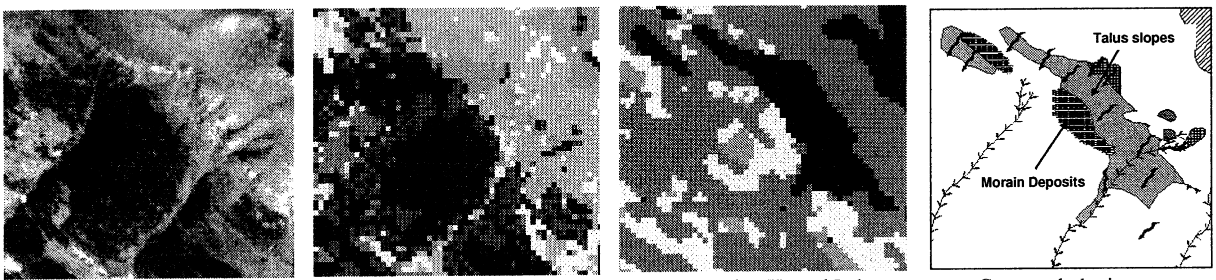


Figure 3: Process flow

The forest/non-forest mask was identified by a slicing of IRS-1C pan image. The classification of forest and non forest areas was performed using Landsat TM image (bands 1,2,3,4,5,7) dated 01/06/1996, topographically corrected using the Minnaert algorithm. The Isodata unsupervised classification algorithm with a maximum of 20 spectral classes was applied. The interpretation of the spectral classes was carried out through auxiliary data and ground truth. The verification of the classification results was performed on pixel and region basis. The number of reference samples for each class was around 30 areas (with a minimum size of 9 pixels). The different number of reference samples was decided in accordance with the class dimension, spectral variability and class importance. The erosion model needed a calibration based on a geological ground survey consisting in 115 points spread over all the test site with an average density of 0.43 points per Km^2.

5.2 Results

The classification accuracy of forest/non-forest mask was 97% (kappa coef. 0.93) while forest type accuracy yielded 98% (kappa coefficient: 0.89); forest crown closure 85% (kappa coef. 0.75) and non-forest classes accuracy was 81% (kappa coef. 0.76).
The main issue of the FSTAB erosion risk model was the Mass Erosion Hazard Index (MEHI). MEHI was computed at a pixel resolution of 30 meters over all the test site a part from pure rocks areas and slopes deeper than 45% because on these areas rock falls are prevailing over mass erosion and these phenomena are too different to be described in the same model. It must be pointed out that the FSTAB differs from other erosion models because it does not provide an erosion rate index, which would not in any case help preventing natural disasters, but a parameter representing the propensity towards the generation of mass erosion. The assessment of results was therefore based on comparisons both qualitative and quantitative of MEHI vs. the geomorphology because it was the most significant available information about the actual and potential erosion risk in the test site area (Figure 4).



IRS-1C Pan image | ALPMON Land Cover | Mass Erosion Hazard Index | Geomorphologic map

Figure 4: Checking the result of the erosion risk model against geomorphologic reference map

5.3 Conclusion

This feasibility study was aimed to assess how remote sensing can give contributions to the evaluation of erosion risk in alpine environment. Land cover parameters were selected to satisfy both the general requirements of ALPMON and the specific needs of erosion risk assessment, like the estimation of pasture density, which was classified into three density classes: 10-30%, 30-60%, > 60%. These density classes were generally suitable for the erosion risk assessment a part from the case of talus slopes covered by very low density grassland which in many cases were classified as rocks. Talus slopes play an important role in the genesis of debris flows, therefore their confusion with rocks produces a fake decrease in erosion risk. Further, the geometric resolution of Landsat TM, even if combined with IRS-1C Pan, was not detailed enough to detect the presence on the surface of potentially unstable incoherent materials (e.g. debris flows). The FSTAB erosion risk model demonstrated to account for several mass erosion phenomena and the sub-model component DA, built over a statistical analysis of geological ground survey and extrapolated to the whole test site area using land cover and other auxiliary distributed data, allowed a detailed stability zoning of the test site area on the basis of soil static conditions.

6 OUTLOOK

The project had to cope with some constraints that were mainly related to the insufficiency of data sources, but also of available processing algorithms. Due to some failures of announced satellite systems it was not possible to use very high resolution satellite data in the project. The spatial resolution range from 1-5m is expected to significantly improve the classification of small vegetation patterns as they are typical for alpine areas especially above the forest border. As well in most cases the resolution of digital elevation models (approx. 25m) is too coarse to allow more detailed geomorphological parameters. Additionally, it proved to be a limiting factor with respect to the topographic normalisation of the satellite images, causing artefacts in the corrected images. The quality of radiometric correction of the satellite images was further restricted by the methods available during the project time. This aspect is essential especially when working in alpine terrain. Due to the interrelations between topography and atmosphere under the special alpine conditions it seems necessary to combine both corrections (Sandmeier & Itten., 1997). Meanwhile the software package ATCOR3, developed at the DLR (Richter, 1998) has solved this problem.

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REFERENCES

Achermann, G. 2000. The influence of red deer (Cervus elaphusL.) upon a subalpine grassland ecosystem in the Swiss National Park. Diss ETH Nr.13479, Zürich.

Almer A., Raggam H. and Strobl D., 1991. High-Precision Geocoding of Spaceborne Remote Sensing Data of High-Relief Terrain. *Proceedings ACSM/ASPRS/Auto Carto Annual Convention*, Vol. 4, pp. 183 - 192, Baltimore, Maryland, March 25-29, 1991.

ALPMON1997. ALPMON project homepage, Graz, Austria. http://dib.joanneum.ac.at/alpmon.

Boughton, W.C., 1989. A Review of the SCS Curve Number Method. Aust. J. Soil Res. 27 p.511-523.

Carrara A., Cardinali M., Guzzetti F., 1992. Uncertainty in assessing landslide hazard and risk. ITC Jour., v. 1992:2, 172-183 Analysis Methods for assessing landslide risk: recent developments. Vth Int.

Jensen J.R., 1996. Introductory Digital Image Processing: a remote sensing perspective. Upper Saddle River, New Jersey, 316 p.

Leuzinger, E., 2000. Raumnutzung der Weide Stabelchod im Schweizerischen Nationalpark durch Rothirsche. Diplomarbeit Universität Zürich, in prep.

Richter, R., 1998. Correction of satellite imagery over mountainous terrain; Applied Optics, Vol. 37, No. 18, 4004-4015
Rowbotham D.N., Dudycha D. , 1998. GIS modeling of slope stability in Phewa Tal watershed, Nepal. Geomorphology 26:151-170.

Sandmeier, St., Itten, K.I., 1997. A Physically-Based Model to Correct Atmospheric and Illumination Effects in Optical Satellite Data of Rugged Terrain. IEEE Transactions on Geoscience and Remote Sensing:35(3):708-717.

Shroder J.F., Bishop M.P., 1998. Mass movement in the Himalaya: new insights and research directions.

Steinnocher, K., Aubrecht, P., Schmitt, U., 2000. Potential of automatic classification in Alpine areas for supporting the update of CORINE landcover. *Proc. ISPRS, Amsterdam, July 2000*, in prep.

Takagi, T. and Sugeno, M. 1985. Fuzzy Identification of Systems and Its Applications to Modeling and Control, IEEE Transactions on Systems, Man, and Cybernetics, 151:116-132.

Zoller, H., 1995. Vegetationskarte des Schweizerischen Nationalparks, Erläuterungen, Parc Naziunal Svizzer, SANW/ASSN, Nr. 85, Zernez.