The Derivation of Indicators for Landslide Detection Using Very High Resolution (VHR) Satellite Imagery

Die Ableitung von Indikatoren aus sehr hochauflösenden Satellitendaten zur Erkennung von Massenbewegungen

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Abstract

Currently existing very high resolution satellite remote sensing systems offer an opportunity to extract land surface information that until recently could only be derived from aerial photographs or by extensive field work. Within the EU funded project ASSIST (Alpine Safety, Security & Informational Services and Technologies) a test site has been defined in a high mountain terrain in the western part of Tyrol/Austria. This region is prone to many natural hazards, i.e. landslides, flooding and snow avalanches. For instance flooding caused heavy damage on the infrastructure and settlements in August 2005 disrupting the important Arlberg railway route for more than three months.

The focus in this investigation is the identification of parameters and/or indicators for natural hazards with special emphasis on landslides research. In order to fulfil these tasks QUICKBIRD data seem to be an adequate data source with its high spatial resolution of 60 cm in the panchromatic mode and an additional four multi spectral band range with 2.4m resolution. The derivation of detailed land use coverage can be performed on a catchment area basis due to the coverage of approximately 300km². A hybrid approach – supervised classification and visual interpretation - is foreseen for the classification of this kind of data with special emphasis on the development of automatic classification tools. The methodology has to integrate algorithmic background in the field of texture calculation and feature extraction. Expected results are the segregation of land cover classes especially important for landslides research and have hardly been derived from former medium resolution standard remote sensing images. Furthermore, digital elevation models of different resolutions will be utilized to extract additional information. It is assigned to incorporate results from different data sources as input data to landslide susceptibility maps based on statistical models.

Key Words: landslide, QUICKBIRD, classification, ASSIST, texture, land cover, Austria.

Zusammenfassung

Die jüngste Generation der neuen hochauflösenden Satellitendaten ermöglicht eine verbesserte Ableitung von Landbedeckungsparametern wie sie bisher nur mit Luftbildaufnahmen oder durch Geländebegehungen möglich waren. Im Rahmen des EU Projektes ASSIST (Alpine Safety, Security & Informational Services and Technologies) wurde eine Testregion im hochalpinen Gelände im Raum Landeck, Tirol/Österreich definiert. Diese Region ist aufgrund ihrer hohen Reliefunterschiede besonders vielen Naturgefahren, wie Murgängen, Wildbächen und Lawinen ausgesetzt. Durch die starke Nutzung durch Besiedelung, Tourismus und Verkehr können Naturgefahren in dieser Region wesentlich mehr Schaden anrichten als in vergleichbaren, weniger erschlossenen Gebieten. So hat beispielsweise das Hochwasser im August 2005 großen Schaden an Siedlungen und Infrastruktur angerichtet.

Das Ziel dieser Untersuchung ist die Identifikation von Indikatoren speziell für Murgänge. Da die bestehenden Daten nicht genau und/oder aktuell genug und Feldbegehungen im alpinen Gelände schwierig und teuer sind, sollen sehr hochauflösende Satellitenbilder (Quickbird) diese Informationen liefern. Quickbird verfügt über eine Auflösung von 60 cm im panchromatischen und 2.4m im multispektralen Bereich. Basierend auf diesen Daten wird ein hybrider Ansatz verfolgt, der aus automatischer Klassifikation und visueller Interpretation besteht. Der automatisierte Teil beinhaltet Algorithmen der Klassifikation, der Texturparameterableitung und der Segmentierung. Neben den optischen Daten stehen Höhenmodelle verschiedener Auflösungen zur Verfügung. Diese werden für die Ableitung von relevanten Parametern verglichen. Aus allen abgeleiteten Datensätzen werden schließlich mit Hilfe von verschiedenen statistischen Modellen Gefahrenkarten erstellt.

Schlüsselwörter: Massenbewegung, QUICKBIRD, Klassifikation, ASSIST, Textur, Landbedeckung, Österreich.

1 Introduction

High mountainous regions are challenging to human society in many senses. For centuries, people living in these areas had to contend with the unfavorable conditions of hazardous rocks, the settling on steep slopes, the cultivation on sparse agricultural land or the force of transporting goods on endangered paths or roads. Moreover, these circumstances have also strongly influenced the way how information in such an extreme environment has been collected for scientific investigations. That means, cumbersome working procedures taking much of manpower and therefore generating high costs. To overcome these drawbacks, remote sensing imagery can be used and help saving a significant amount of these investments.
Currently existing very high resolution satellite remote sensing systems offer an opportunity to extract land surface information that until recently could only be derived from aerial photographs or by extensive field work. Within the EU funded project ASSIST (Alpine Safety, Security & Informational Services and Technologies) a test site has been defined in a high mountain terrain in the western part of Tyrol/Austria (see Fig. 1). This region is prone to many natural hazards, i.e. landslides, flooding and snow avalanches. The testsite encompasses the "Stanzer-" and the "Paznaunvalley". It is a high-mountainous region with height differences of almost 2400 m and at the same time, the area is well populated and extensively used for transport and touristic purposes. Therefore, natural hazards are typically more severe than in other, less developed regions. For instance flooding caused heavy damage on the infrastructure and settlements in August 2005 disrupting the important Arlberg railway route for more than three months.

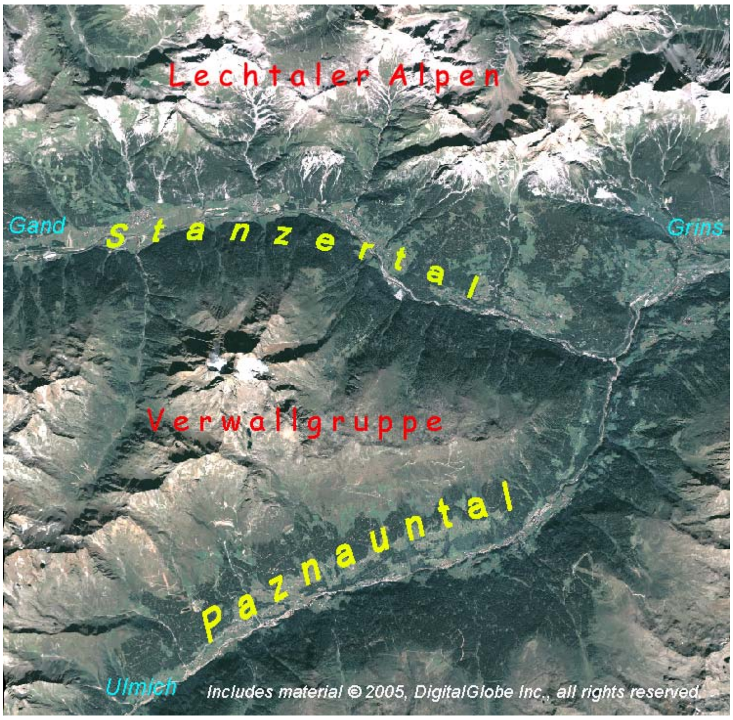


Figure 1. Quickbird Image from Testsite Landeck / Tyrol.

2 Requirements

The detection of landslide risk zones is a very labour-intensive work in the field and/or from visually interpreting remote sensing site. If one is aiming at facilitating this work, the first step is to analyse the requirements - dependent on data available.
Generally, the occurrence of mass movements is influenced by many quasi-static factors expressed by terrain parameters which can be attributed to one of the following main categories:
1. Geology,
2. Geomorphology and Topography
3. Land cover

Landslides are usually triggered by events or triggering factors such as abundant rainfall, rapid spring snow melt or earthquakes. For the generation of a basic zoning map of mass movement susceptibility, triggering factors have not be taken into account. However, indicators for the quasi-static factors should be extracted as detailed and as automatic as possible. Geologic information can be obtained from geological maps, if they are integrated in the GIS environment together with the other information sources. Very high resolution imagery is – based on its detailed spatial information - one possibility to derive the required land cover as well as partly the geomorphological information. The use of stereo images would increase the information content, as three dimensional information about the vegetation (vegetation height) can be obtained from stereo images in combination with a DEM. However, in the present case, no stereo data is available. The use of a digital elevation model (DEM) either from the National Land Survey (BEV in Austria) or from Laserscanning is strongly recommended for the derivation of many parameters. The most important indicators, relevant for landslide detection, are shown in Table 1. Some of these parameters can be obtained by automatic approaches, while others still need fully or partly visual interpretation.

Table 1. List of the Parameters to be Derived by Hybrid Methodology; i.e. automatically (auto) and/or by visual interpretation (vis).

Main category	Sub-category	Parameters	Procedure
1. Geology	Bedrock lithology		*vis (partly)*
	Loose material		*vis (partly)*
	Structural orientation		*vis (partly)*
	Tectonics		*vis (partly)*
2. Geomorphology	Basic geomorphometric features	Height	*auto*
		Slope	*auto*
		Aspect	*auto*
		Curvature	*auto*
		Slope length	*auto*
		Surface roughness	*Auto*
	Erosion Features	Undercutting of slopes	*vis*
		Scarps	*vis*
		Transport zone	*auto/vis*
		Deposition zone	*auto/vis*
	Hydrology	Drainage – microdrainage	*auto/vis*
		Ponds – elongated	*vis*
		Wet areas	*vis*
	Permafrost	Permafrost areas	*auto (Models)*
		Rockglacier	*vis*
3. Landcover	Vegetation	Broadleaf Forest	*auto*
		Coniferous Forest	*auto*
		Green alder	*auto/vis*
		Meadows, pastures, shrubs	
	Non-vegetation	Snow	*auto*
		Ice	*auto*
		Water	*auto*
		Talus scree fine	*auto*
		Talus scree coarse	*auto*
		Rock	*auto/vis*

These parameters support the detection of landslide risk zones, but up to now, they had to be derived in a time consuming and cost-intensive way. Therefore, the main goal of this study is to develop a methodology to derive as many parameters as possible using automatic procedures. Some important geomorphometric features can be processed from the DEM, and will be incorporated into the classification scheme. They encompass the parameters height, slope, exposition, curvature (convex vs. concave), slope length and roughness.

3 Data Used

The data selected for this study is based on the requirements given above. For the basic geologic information, a geological map at a scale of 1:50 000 is digitized and used as one important information layer. For deriving the geomorphological features, two data sets are compared: the standard DEM with a 25 m resolution and a detailed Laserscanning DEM with a resolution of 1m (further details are given in Table 2). One question to be answered in this investigation is: "what quality improvement can be expected by using a very detailed DEM from Laserscanning compared to standard DEM?" For the derivation of the Landcover parameters, VHR data is necessary, as the land cover information needs to be obtained in detail. The data source can be aerial imagery as well as VHR satellite data. In this study, a monotemporal QUICKBIRD scene has been ordered for this purpose. The data specifications of this imagery are given in Table 2.

Table 2: Technical Specification of the QUICKBIRD Imagery.

Parameter	QUICKBIRD	Parameter	Laserscanner Toposys
Acquisition date	**06.09.2005**	Acquisition date	**12.10.2005**
Orbit	**470 km/ polar**		
Coverage	**16x16 km**	Swath width	**about 760 m**
Spatial resolution	**0.61 m Pan, 2.5 m MS**	Point density	**2/m²**
Record probability	**20 days**	Overlap	**30%**
Spectral bands [µm]	**Bd 1 0.450 - 0.520** **Bd 2 0.520 - 0.600** **Bd 3 0.630 - 0.690** **Bd 4 0.760 - 0.900** **Pan: 0.450 - 0.900**		
Stereo capability	**Along track**		
Look angle	**± 45°**	Field of View	**12°**
Organisation	**www.Digitalglobe.com**	Organisation	**TerraDigital**

4 Methodology

As the testsite encompasses a height difference of almost 2400m it is evident that there are manifold surface types. Thus, the applied methodology had to be elaborated in a flexible way involving different approaches for the derivation of the assigned parameters and the existing data sets – geologic map, QUICKBIRD image and DEM. The methodology is based on a hierarchical approach, which uses standard software, where possible, but also recently developed algorithms. The first steps in processing remote sensing data are always the orthorectification and further necessary pre-processing. The orthorectification was performed as an accurate DEM-based geocoding procedure using the Remote Sensing software package Graz (RSG). This geocoding has been applied for both the multispectral and the panchromatic QUICKBIRD scene. Based on the result of the geocoding, the following processing steps have been performed.

4.1 Pansharpening

The QUICKBIRD imagery has been recorded in panchromatic and multispectral modes with a spatial resolution of 0.61m and 2.4m at Nadir, respectively. The main goal of pansharpening is to combine both the finer resolution of the panchromatic image with the color of the multispectral image without changing the original grey values. For this task, some algorithms have been developed or modified, and applied on the data.
Standard algorithms like “Brovey Transform”, as implemented in Erdas Imagine, only work properly for three multispectral bands. If calculated on the four-band QUICKBIRD image, the original grey values are severely changed and, therefore, the result cannot be considered to be of use for the forthcoming classification. In order to overcome this drawback, the “Brovey Transform” has been modified to a so called “adaptive Brovey transform”. This modification allows the use of four multispectral bands, if they are well correlated with the panchromatic band. This is true for QUICKBIRD images, as the panchromatic channel covers the same spectral range than the multispectral bands together (see Table 3 Quickbird data). A comparison of different pansharpening approaches can be found for example in Hirschmugl et. al. (2005).

4.2 Pixelwise Classification

The first classification step was focused on the derivation of a coarse landcover layer by applying a pixelwise supervised classification. Some 50 reference areas have been extracted from the pansharpened image by visual interpretation. This processing step is a straightforward task, as it could be performed in short time (see Fig. 2). Subsequently, a spatial merging algorithm was applied on the result to obtain a more homogeneous appearance of the individual classes (see Fig. 2, right image), i. e. to remove the “salt and pepper effect”. This algorithm is used to merge adjacent regions according to their spatial properties. Regions which are smaller than the specified size or regions with an outline shape higher than a given threshold are merged. The similarity to neighboring class, with which the object could be merged, is calculated based on its neighborhood properties.

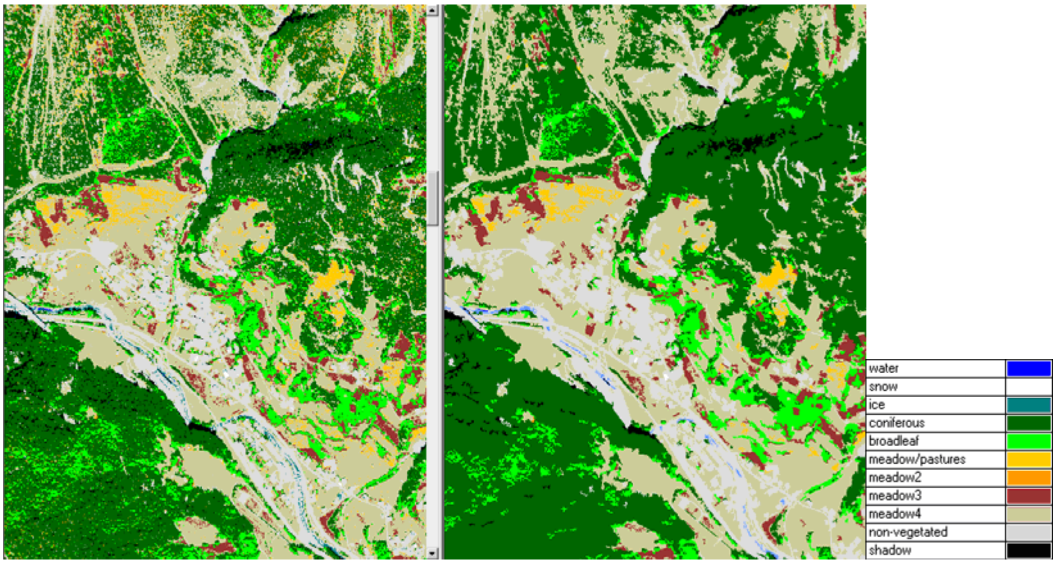


Figure 2. Pixelwise Classification of QUICKBIRD image (left image); spatial filtered image (right image).

Based on this result, the following main landcover classes have been derived successfully (see Fig. 2): water, snow, ice, broadleaf forest, coniferous forest, four types of meadows, non-vegetated areas and shadow. According to the requirements discussed, the classes water, snow, ice, broadleaf forest, coniferous forest, and shadow can already be used for the final result. However, there are still some uncertainties and some difficult areas, where this first classification is too coarse or too inaccurate. One example is the exact delineation of the upper forest border. Furthermore, for the classes “meadow” and “non-vegetated areas” a more detailed differentiation has to be performed in the next phase.

4.3 Texture-Based Classification

The pixelwise classification based on the spectral values had shown its limitations for deriving more detailed classes. To accomplish the requirement of a more detailed separation within e. g. the class “non-vegetation”, the textured information of the panchromatic image can be used. This is performed using a texture algorithm. This algorithm is used to calculate certain statistical values based on mean or variance within the sectors surrounding a pixel. The radius and the number of sectors (or wedges) can be specified by the user. The content derived from this texture layer can be used to improve the classification, e.g. the differentiation of fine talus scree versus coarse talus scree. Additionally, the filter was supporting the determination of the upper forest border, which is essential to quantify the forest area, especially in the higher elevated regions. Furthermore, the upper forest border line is helpful to differentiate between “non-vegetation” areas within the image. For instance, non-vegetation areas could be settlements and streets in the valley, whereas the same spectral response from above the forest border line shows talus scree and other eroded planes.

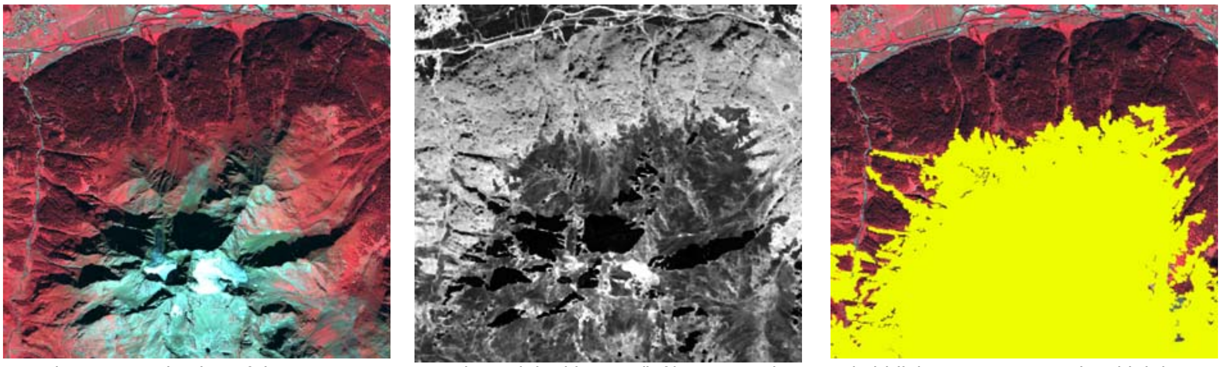


Figure 3. Derivation of the Upper Forest Border; original image (left); Textured Image (middle); Upper Forest Line (right).

In Figure 3 the processing steps for the derivation of the upper forest border is displayed. It can be recognized that some small errors remain in the shadowed areas. They have to be corrected by visual interpretation, but the effort for this correction is low, because most of the border line could be correctly derived by the automatic procedure. Figure 4a and Figure 4b proof the successful application of this processing step in more detail.

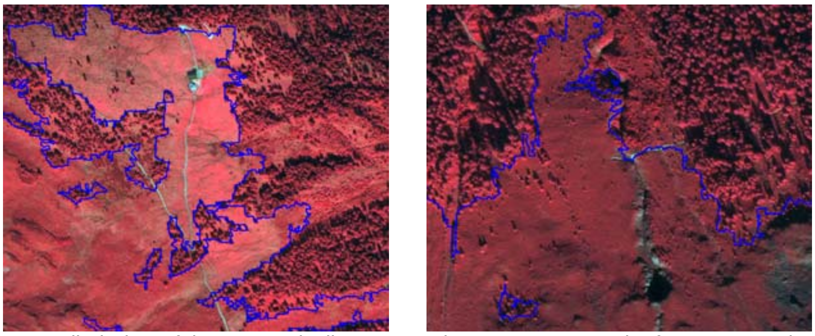


Figure 4. Detailed View of the automatically generated Upper Forest Border for two example regions

Due to their different infiltration capacities and potential for providing material for landslides it was one more goal to separate coarse talus scree from fine talus scree. Fine talus scree can be more easily moved downwards than coarse blocks. The separation was performed again based on the texture information, which is inherent in the panchromatic image. An example of this separation is displayed in Figure 5. This result will be used as one variable for the calculation of the susceptibility map.

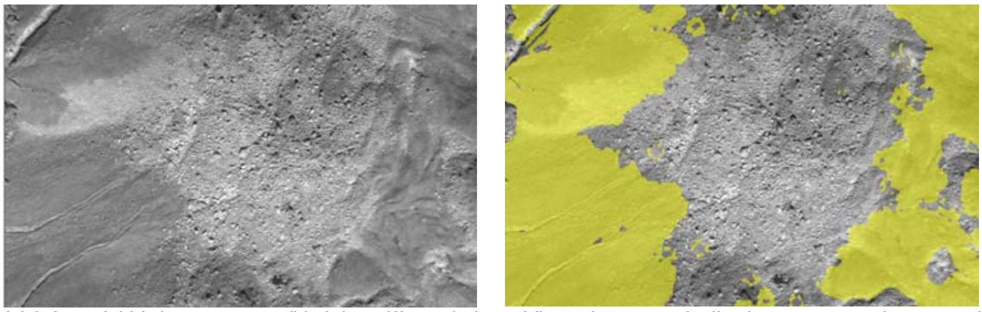


Figure 5. (a) left: Quickbird Pan Image; (b) right: Differentiation of fine talus scree (yellow) vs. coarse talus scree (no color).

4.4 Morphometric Terrain Parameters, Visual Interpretation

The use of a DEM in high mountainous regions is a prerequisite in the overall processing; e.g. this encompasses the geocoding as well as the generation of geomorphometric derivates. As already mentioned, in the present investigations two different DEMs are available, i.e. a 25m grid and a high resolution 1m grid. Some parameters are foreseen to be deduced from the DEMs as for instance, elevation, slope and its length, exposition, curvature, roughness and drainage. The differences are obvious in Figure 6: the high resolution DEM shows much more details and accuracy enabling a more precise analysis of the surface. The shaded relief of the Laserscanner data represents well all forest roads, ravines, small ridges and undercutting of slopes, while the 25m DEM only roughly shows the slopes and very coarse geomorphic features.

Fresh undercutting of unstable slopes can clearly be interpreted by an expert in the 1m DEM, while it can hardly be discriminated from old, stable slopes in the 25m model. Also the area of the landslide itself, which was triggered by these undercutting processes and has severly damaged the road, is not recognizable in the lower resolution DEM. A further comparison regarding slope and aspect calculations was performed. Table 3 shows the area statistics for the two data sets. Basically, the differences are not as obvious as they are in the image, because the statistics over a larger area equalize some of the differences. However, the more accurate differentiation in the slope classes is reflected in the figures: the flat as well as the very steep areas are well represented in the Laserscanner model, but evidently omitted in the coarse DEM.

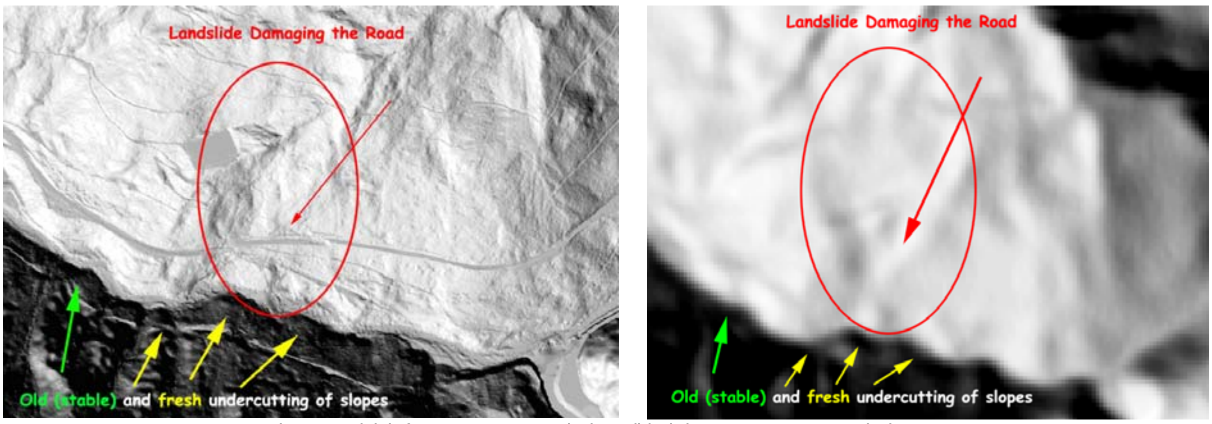


Figure 6. (a) left: DEM 1m Resolution; (b) right: DEM 25m Resolution.

Table 3: Comparison of slope and aspect calculations from 25m and 1m DEM

Aspect classes (°)	DEM 1m (%)	DEM 25 m (%)	Slope classes (°)	DEM 1m (%)	DEM 25 m (%)
0-45	12,71	14,25	**0-10**	9,55	4,97
45-90	8,98	7,11	**10-20**	9,93	10,11
90-135	13,26	13,91	**20-30**	19,86	22,50
135-180	18,30	17,65	**30-40**	33,26	37,49
180-225	15,14	16,13	**40-50**	18,69	20,63
225-270	8,59	7,72	**50-60**	6,70	4,18
270-315	13,77	16,12	**60-70**	1,79	0,11
315-360	9,24	7,11	**70-80**	0,21	0,00
			80-90	0,00	0,00
			>90	0,00	0,00

Not all of the required indicators, which are inherent in the image, can be derived by automatic processing, this belongs e.g. to Rockglaciers, elongated ponds or wet areas (see Fig. 7). For this purpose visual interpretation is still an adequate procedure. An experienced interpreter should be able to derive some more indicators from the high resolution QUICKBIRD image.

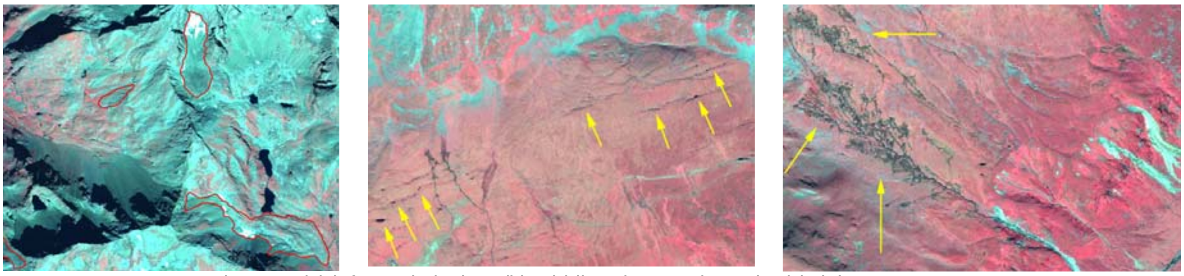


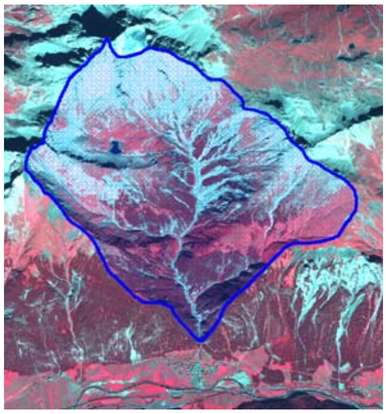
Figure 7. (a) left: Rockglacier ; (b) middle: Elongated Ponds; (c) right: Wet Areas.

4.5 Model Based Hazard Analysis

The first step in analyzing the susceptibility of such processes is performed by using an automatically derived catchment area (basin), which was struck by the 2005 flooding event. For the defined area, all available information is calculated and leads to certain statistics describing the catchment (as an example see Table 4). Based on this analysis and on further information (e. g. geology), models can be trained. Clearly, the different factors are of different importance, which is considered by using for example different weights. In the final step, catchments with similar statistics can be identified, which can then be regarded to be at risk of landslides.

Table 4: Land cover and terrain statistics for a catchment area (shaded and delineated in blue in the lower right corner) of a past landslide event

Class – automatic classification of Quickbird data	**Area [%]**	**Slope classes**	**Area [%]**	**Aspect classes**	**Area [%]**
Lake	0,17	**0-10**	1,06	**0-45**	3,75
Ice (Glaciers)	0,11	**10-20**	3,81	**45-90**	8,98
Snow	0,27	**20-30**	14,86	**90-135**	15,11
Non-Vegetation	1,67	**30-40**	43,77	**135-180**	24,17
Rhododendron	0,21	**40-50**	27,56	**180-225**	23,62
Coniferous forest	10,82	**50-60**	7,84	**225-270**	15,91
Deciduous forest	0,56	**60-70**	1,06	**270-315**	7,15
Mixed forest	1,42	**70-80**	0,04	**315-360**	1,30
Dwarf mountain pine	3,96	**80-90**	0,00		
Fettwiese	4,68	**>90**	0,00		
Matten (1)	0,37				
Meadow	19,00				
Matten (2) Vernässung	17,58				
Talus scree, partly with vegetation	0,04				
Houses	0,00				
Shadow	0,61				
Non-vegetation above forest border	38,51				



5 Discussion and Outlook

Beside the remote sensing data only fieldwork-based high-quality maps, including geotechnical and hydrogeological information, can satisfy the noticed data requirements - which may be a decisive problem in many alpine regions where such data are not available. Following this fact, the parameters derived from the VHR satellite data and from the available DEMs can be considered as important data base and in some regions are the only available information sources. However, the quality of the derived parameters still needs to be evaluated in detail. Geological data required can be derived from remote sensing data only to some extent, therefore, geological maps have been used in addition. Subsequently, a suitable model for risk area analysis has to be chosen. Different models for the assessment of hazards and risks are available. Two main groups can be distinguished: 1. decision tree models and 2. statistical models. The advantage of the first models is their controllability, which can also be seen as drawback depending on the reliability of the chosen thresholds. Statistical models are less prone to such errors. Based on the parameters derived as described in the sections above, different statistical approaches (e. g. “weights of evidence method”, “susceptibility analysis”) will be used aiming at assessing the landslide hazard in the study area. All methods for evaluating hazard and risk values are error-prone; the statistical approach nevertheless has proved to be the most reliable method for the assessment of large areas. Landslide hazard evaluation becomes as objective an operation as possible since the instability determinants and their interrelations are evaluated on the basis of a multivariate statistical model. Generally, it is supposed that future events would occur under similar geo-environmental conditions, which have led to the past ones. Therefore, retrospective data can be used as a “training samples” for determining areas with a high probability for future events. A mass movement distribution map inclusive the past events, therefore, can be considered as an important input, as it shows the distribution of the phenomena that one wants to predict (Carrara et al. 1992, Van Westen 1993). Furthermore, information is needed on the main factors responsible for instability conditions, e.g. rock composition and rock structure, groundwater and surface water conditions, slope geometry and angle, slope geomorphic processes, land cover and human activity. Clearly the resulting quality of these functional models is directly dependant on the accuracy, i.e. spatial resolution and classification accuracy, and quantity of data collected. This is again an important argument for using VHR remote sensing data sources. Finally it has to be stated, that the modeling task is that part of the project work which is still lying ahead. It will be performed in the forthcoming project year based on the already derived parameters and will finally lead into the generation of risk analysis maps.

Acknowledgements

The authors gratefully thank the ASI (Alpine Safety and Security) and the “Landesregierung Tirol” for their collaboration and support to the investigations.
The investigations described in this paper were performed within the EU co-financed ASISST project (Alpine Safety, Security & Informational Services and Technologies).

References

Buchroithner, M.F. and Granica, K. (1997): Applications of Imaging Radar in Hydro-Geological Disaster Management: A Review. Remote Sensing Reviews, Vol. 16, Harwood Academic Publishers, Graz/Dresden, pp. 134.

Carrara, A., Cardinali, M. & Guzzetti, F.: Uncertainty in assessing landlide hazard and risk.- ITC Journal 1992-2, pp.172-183, Enschede 1992.

Granica, K., Schardt, M. and Gallaun, H. (2000): Monitoring of Protection Forests by Means of SPOT4 Satellite Data, 20th EARSeL Symposium, 14th – 16th June, 2000, Dresden, Germany.

Schardt, M., Granica, K., Hirschmugl, M., Luckel, W. and Klaushofer, F. (2004): Mapping Protection Forests in the Province of Salzburg Using Remote Sensing. Proc. Göttingen GIS & Remote Sensing Days 2004, Göttinger Geographische Schriften.

Hirschmugl, M., Gallaun, H., Perko, R. & Schardt, M. (2005): “Pansharpening” – Methoden für digitale, sehr hoch auflösende Fernerkundungsdaten. Strobl/Blaschke/Griesebner (Hrsg.): Angewandte Geoinformatik 2005. Proc. of 17th AGIT Symposium (06. – 08. 07. 2005), Salzburg. Verlag Wichmann, Heidelberg, pp. 270 – 276.

Van Westen, C.J.: GISSIZ – Geographic Information Systems in Slope Instability Zonation.- ITC Publication Number 15, Vol. 1, Enschede 1993.

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