GeoInformation in Europe, M.A. Gomarsca (ed.)

Digital terrain models and their usability to landslide risk assessment and visualisation

M. Hirschmugl, K. Granica, H. Proske, M. Wurm, A. Almer, T. Schnabel
J. Raggam & M. Schardt
JOANNEUM RESEARCH, Institute of Digital Image Processing, Graz, Austria

Keywords: hazard assessment, geomorphology, geo-visualization, remote sensing, landslides

ABSTRACT: Digital Terrain Models (DTMs) are an important information source for many remote sensing and GIS applications. In this paper, the usability of DTMs from different sources for the mapping of landslide susceptibility as well as for visualization purposes is evaluated. The work was done within the scope of the ASSIST (Alpine Safety, Security & Informational Services and Technologies) project and results were exchanged over the GMOSS (Global Monitoring for Security and Stability) Network of Excellence.

An Alpine testsite has been selected in a high mountain terrain near Landeck/Tyrol/A. This region is prone to many natural hazards, i.e. landslides, floods and snow avalanches. A DTM with a spatial resolution of 25 m and a very high resolution (VHR) LiDAR (Light Detection And Ranging) DTM offering a spatial resolution of 1m were used to identify geomorphometric parameters as indicators for landslides susceptibility mapping. Additionally to these indicators, also landcover information from a QUICKBIRD satellite image classification and geological data extracted from a geological map are used in this testsite. The differences between the two DTMs in the context of assessing risk zones based on statistical models are evaluated and compared to visual aerial image interpretation of risk zones. Additionally, a region in Kashmir was selected as a second testsite to evaluate the usability of a DTM derived from stereo Spot scenes for the derivation of landslide indicators. Furthermore, an overview is given on the usability of the different DTMs to be used for geo-visualization.

1 INTRODUCTION

The detection of landslide susceptibility zones is a very labour-intensive work either performed in a field campaign or by applying visual interpretation on remote sensing data. Generally, the occurrence of mass movements is influenced by quasi-static factors such as the inclination of the slope or the land cover type and also by dynamic factors like rainfall. Quasi-static means, that these factors are normally stable over a period of time. They can be attributed to one of the following main categories: (i) geology; (ii) geomorphology / topography; (iii) land cover.

The triggering factors (dynamic factors) for an actual landslide event are temporal ones such as abundant rainfall, rapid spring snow melt or earthquakes. For the generation of a basic zoning map of mass movement susceptibility, triggering factors are mostly not taken into account.

Due to time and cost restrictions, indicators for the quasi-static factors should be extracted as automatic as possible, but with sufficient detail. Geologic information can be obtained from geological maps integrated into a GIS environment. The use of a digital terrain model (DTM) is the main information source for the derivation of the required geomorphological features. Very high resolution imagery (such as QUICKBIRD or IKONOS imagery) is one possible data source to derive the required land cover information as well as some additional geomorphological features with high spatial and thematic detail.

Within the frame of landslide susceptibility mapping, the specific aims of this study are:

- to test different DTMs with respect to their usability to derive geomorphometric features
- to evaluate the geomorphometric features regarding their use for susceptibility modeling
- to assess the applicability of different DTMs for data visualization.

2 DATA

The basic geologic information was taken from a geological map at a scale of 1:50 000 (Austrian Geological Survey GBA), the land cover parameters were derived from a QUICKBIRD scene. The geomorphometric features were calculated based on DTMs from different sources with different resolutions. The first data set to be tested is a DTM from the Austrian national land survey 'BEV'. This DTM shows a varying accuracy depending on the complexity of the terrain. The accuracy is stated to be about ±2–5 m in open and flat areas and ±10–25 m in mountainous terrain or beneath forest (according to BEV 2007). Since landslide activity is linked to a certain inclination and as large parts of the testsite area are covered with forest, the lower accuracy values are more reasonable for the current study. The second available DTM was derived from laserscanner (LiDAR) data. The general accuracy of LiDAR DTMs depends on the point density of the

Table 1. Technical specification of the remote sensing data (SPOT stereo – Kashmir and LiDAR – Austria).

Parameter	SPOT PAN triplet			Parameter	Laserscanner Toposys
Acquisition date	6.10.2004	21.10.2005	18.12.2005	Acquisition date	2002/2003
Orbit		197/281		Swath width	about 400 m
Spatial resolution		Pan: 5 m		Point density	4/m^2
Spectral resolution		Pan: 0.61–0.68 µm		Overlap	30%
Look angle	+11.4	−1.8	−28.7	Field of View	14°
Organisation		Spot Image		Organisation	TopoSys

acquisition and on the vegetation cover. LiDAR systems offer good terrain information also beneath forest. The third option used in this investigation was the creation of a DTM by means of stereo-matching.

In the Austrian test site, two data sets are directly compared: the standard DTM with 25 m resolution and a detailed LiDAR DTM with a resolution of 1 m. To evaluate also the applicability of the DTM from multi image stereo matching, an example from the Kashmir region is used. The details of the LiDAR and the Spot stereo data can be found in Table 1.

3 METHODS

In order to integrate the relevant geological information into the landslide susceptibility modelling, the geological units from the available map were merged from original 116 classes to 13 classes standing for distinct properties with respect to landslide occurrence. The classification of landcover parameters was based on orthorectified, topographically normalized and pansharpened QUICKBIRD imagery. A comparison between air photos and satellite imagery for susceptibility mapping can be found in Weirich & Blesius (2006). The methodology encompasses a hierarchical approach starting with a supervised pixel-wise classification using training areas and a maximum likelihood classifier. Subsequently, too small clusters were merged with the neighbouring classes and inherent texture information was used to distinguish spectrally similar classes like coarse and fine detritus. More details on the classification procedure can be found in Granica *et al.* (2007).

3.1 *Obtaining DTMs*

The BEV DTM has been derived by a combination of photogrammetric measurements from airborne imagery and structure information such as ridges and breaklines. The resulting information was then interpolated to a regular raster of 25 m. Details can be found in BEV (2007).

The laserscanner DTM was calculated from the original point cloud by a filtering approach called 'gridbased hierarchical weighting function approach' described in Wack & Wimmer (2002). The aim of the filter is to eliminate buildings and vegetation, leaving only the terrain structures at a resolution of 1 m.

Based on methods described in Raggam *et al.* (2007), a digital surface model (DSM) from a SPOT5 data triplet was generated for the Kashmir testsite. In non-vegetated areas, such a surface model is equivalent to a digital terrain model and can, therefore, be used as such. Due to very poor reference data (maps) and clouds, the DTM from the first matching resulted in poor accuracy of about 60 m. Using the coarse existing SRTM (shuttle radar topography mission) DTM, the pan images could be roughly rectified. With these orthoimages, the matching was performed again and the DTM could be improved to an absolute height accuracy of about 20 m. A reasonable spatial resolution for the output elevation model turned out to be 5 m. Since the aim in this study is not to evaluate the absolute accuracy but the usability for landslide modelling, relative consistency and details are more important than absolute height precision.

3.2 *Deriving geomorphometric features*

The geomorphologic situation can be seen as one of the most important factors for landsliding. At the same time, the details are difficult to be assessed by means of automatic image processing tools. The spatial resolution of the used DTM has to be considered, if geomorphological features like roughness parameters are derived. There are a few different approaches to automatically derive geomorphologic information:

1. Curvature: Curvature is basically the change of slope in any direction. It can roughly be divided into concave, convex and not curved.
2. Downslope curvature: This measure describes the curvature in the direction of the slope. In many cases, downslope facing – convex – forms indicate an enhanced potential for landsliding.
3. Eigenvectors (McKean 2004) measure the variability of slope and aspect in local patches of the DTM. Unit vectors are constructed perpendicular to each cell in the DTM. On this basis, different statistical measures are applied to evaluate the local variability.
4. Hydrological stream net: A DTM can be used to calculate a theoretical hydrological stream net. More details in the DTM lead to a more realistic location of ditches and creeks. The distance to trenches can serve as indicator for landslide susceptibility.

3.3 *Modelling*

According to Hansen (1984) there are two different approaches for hazard zone mapping: (i) direct approaches, also called hazard mapping, mainly based on field work and (ii) indirect methods. The latter calculate the importance of the combinations of parameters occurring in landslide locations and extrapolate the results to landslide-free areas with similar combinations, mainly by statistical models (Van Westen 1993). In this study, both approaches were used. The first approach was used to derive the training and verification data and the second approach was used for the susceptibility analysis per se. Van Westen (2006) stated, that the triggering of different types of landslides (e.g deep-seated rotational slides, shallow translational slides) depends on different parameter combinations. Therefore, different training data sets would have to be created for different types of landslides. Since shallow translational slides are predominant in the study area, the current investigation is restricted to this type. Two different statistical models were used to assess the susceptibility:

1. Weights of evidence (WoE) model. This method was developed by Bonham-Carter *et al.* (1988) for gold exploration in Nova Scotia. Positive and negative weights are assigned to each factor (binary map) using Bayes rules for conditional probability. According to Van Westen (1993), the final product is "*a predictor map giving the posterior probability of the occurrence of landslides for each pixel, which is based upon the unique overlap of all binary input pattern maps*".

2. Susceptibility model. This method (implemented according to the description in Van Westen 1993) also belongs to the group of univariate statistical landslide hazard analysis methods.

The main differences between the two methods are, that for the susceptibility model: (i) no negative weights are derived and (ii) the weights are not logarithmised.

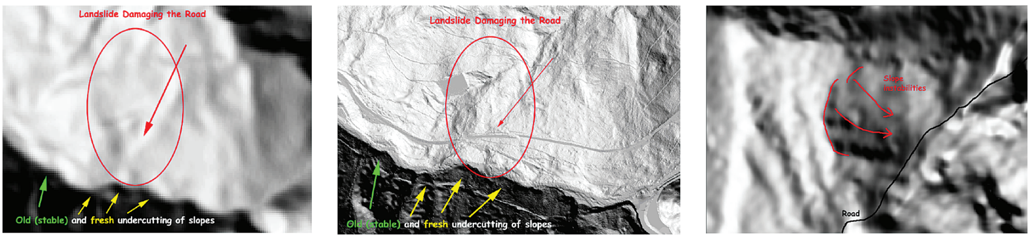
4 RESULTS AND DISCUSSION

Exemplarily, subsets of the resulting three DTMs (about 1400 m × 900 m) are shown in Figure 1 to visualize the quality of the different models. BEV DTM and LiDAR DTM are showing the same area and can therefore be compared directly. Clearly, the LiDAR DTM shows the best result with many details such as roads, creeks, ravines, etc. The SPOT stereo DTM from Kashmir also offers some details, while the BEV DTM is much more generalized. The main weakness of the Spot stereo DTM is the absence of terrain data over areas with dense and high vegetation such as forested areas, because stereo mapping is. However, for areas covered by low vegetation or for bare ground, such a model is an option if no adequate basic DTM is available and a laserscanning campaign is too expensive.

4.1 *Usability of different DTMs for susceptibility modelling*

For the Austrian testsite, the susceptibility modelling with the two models including all derived parameters (land cover, geology, geomorphometric features) was performed and the differences of the resulting maps are analyzed. For the Kashmir test site, only the geomorphometric parameters were calculated and their results compared by on-screen interpretation to those of the Austrian testsite.

It is important to mention, that during the susceptibility analysis, the parameter aspect turned out to be strongly biased and had to be excluded. The reason was found in the geologic situation of the testsite. The area is located at the border between carbonatic rock in the north (=south-facing slopes) and crystalline rock in the south (=north-facing slopes). Since landslides are much more frequent in the carbonate area, a high relevance



(a) BEV DTM (b) LiDAR DTM (c) SPOT4 stereo DTM

Figure 1. Visual comparison of the DTMs (subsets of ∼1400 m × 900 m): (a) and (b) in Austria; (c) in Kashmir.

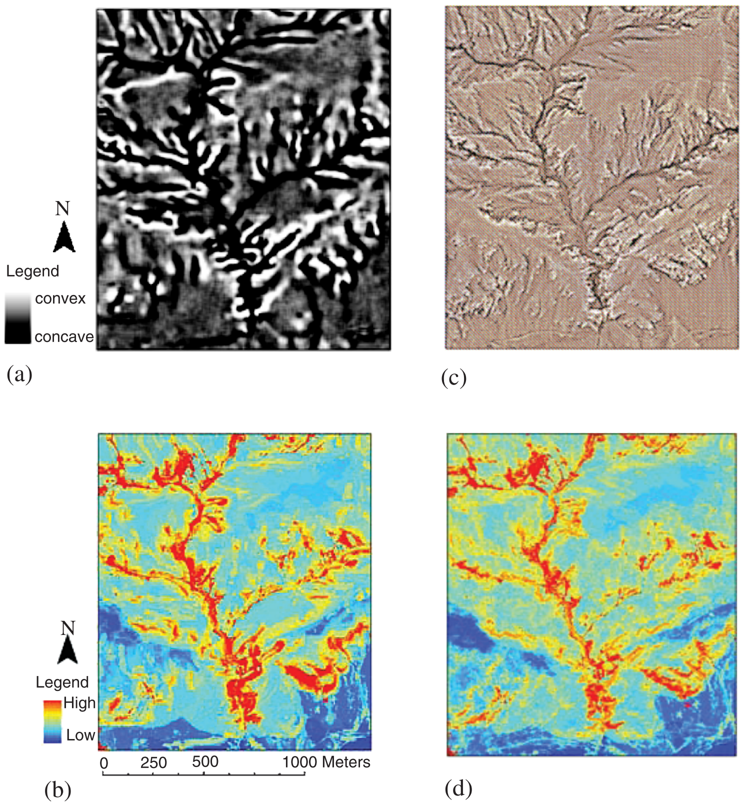


Figure 2. Visual comparison of curvature calculation (above) and result of susceptibility analysis (below). (a) BEV DTM curvature, (b) BEV DTM result, (c) LiDAR DTM curv, (d) LiDAR DTM result.

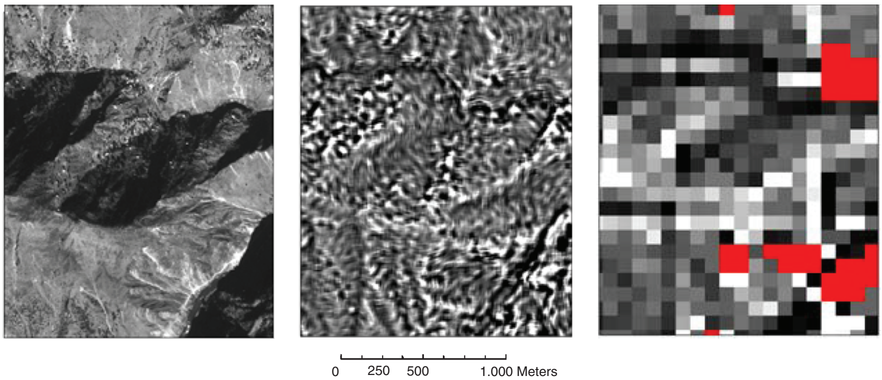
is given to the parameter aspect, although the determinant factor of the landslide distribution is the specific geologic situation.

The general clusters remained the same for the calculation with the BEV DTM and the LiDAR DEM (see Figure 2). However, as expected, the result based on the LiDAR data shows a more pronounced result. Fine structures are better represented in general, mainly due to the differences in curvature and slope calculation. Due to the more detailed structure, the weights for the geomorphometric parameters also changed. For instance, in the WoE model, the class slope 70–90° shows a strong change: from a low weight (0.85) in the BEV DTM to a high weight when using the LiDAR DTM (1.57). The differences in the susceptibility results are moderate: classified to five equal interval hazard classes, the percentages of the different classes are shown in Table 2.

The SPOT stereo DTM is not as detailed as the LiDAR data, but in remote areas where high-resolution DTMs are rare, this DTM can be seen as a valuable data base. The only alternative in remote regions like Kashmir is the SRTM DTM at a resolution of about 90 m. The curvatures calculated from the SPOT stereo DTM and the SRTM DTM are

Table 2. Results of susceptibility mapping for the BEV DTM and LiDAR DTM.

Hazard class	1 (low risk)	2	3	4	5 (high risk)
Calculated with LiDAR DTM [%]	68,87	25,33	2,15	3,10	0,55
Calculated with BEV DTM [%]	75,94	18,95	2,65	2,35	0,11



(a) SPOT image (b) SPOT DTM curv. (c) SRTM DTM curv.

Figure 3. Panchromatic SPOT image (a) and curvature calculated from the SPOT stereo DTM (b) and from the SRTM DTM (c). Red areas = missing data. Legend see Figure 2 a. (a) SPOT image, (b) SPOT DTM curv, (c) SRTM DTM curv.

compared and displayed in Figure 3. The spatial resolution clearly limits the capability of the SRTM DTM: only very rough features are visible. Data gaps occur in both models. Due to better geometric resolution, the SPOT stereo DTM was primarily used in the GMOSS project and only snow- or cloud covered areas were filled with the SRTM DTM.

4.2 *Usability of different DTMs for geo-visualization*

DTMs are of huge importance as basic data for a 3D visualization. Models using data from SRTM or BEV DTMs are only applicable for landscape visualization at a lower resolution. For more detailed 3D models, high detailed DTMs derived from high resolution remote sensing stereo images or laserscanner data are the preferred choice. Additionally, the field of application is a crucial factor for the selection of a DTM. We differ between real-time and pre-processed modelling applications. For real-time applications, VHR DTMs are problematic due to their demands on a performance of high end graphic-cards, although VHR data gives the most realistic visual impressions. Depending on the purpose, there are a lot of software products to create these models, e.g. Visual Nature Studio, Maya, Java. Another option to use DTMs for geo-visualization is by employing currently available OGC-Services. Examples for these are the Web Map Service (WMS), Web Terrain Server (WTS) and the Web 3D Service (W3DS). A WMS provides the data in a raster format in the requested resolution, dimension and format for another application (e.g. Shockwave 3D) that uses it as basic data for creating the model (WMS 2007). The task of WTS is the building of perspective views of geo-referenced data. These exported views are in most cases formats like PNG, GIF or JPEG and not the data itself (WebTerrainServer 2007). W3DS is a portrayal service for three-dimensional geo-data, delivering graphical elements from a given geographical area. In contrast to WMS and WTS, 3D scene graphs are produced. These scene graphs will be rendered by the client and can interactively be explored by the user. The W3DS merges different layers of 3D data in one scene graph (Web 3d Service 2007).

Recent projects have shown the importance of selecting the best suitable DTM for the visualization depending on scale, application, costs and thematic requirements. VHR LiDAR DTMs proved to be best suitable for detailed 3D views including small geomorphologic structures and detailed vegetation, while the BEV DTM is sufficiently accurate for region-wide visualizations for tourism including e.g. hiking routes and 3D flights.

5 SUMMARY

Landslide susceptibility analysis using univariate statistical models is a sensitive task. The selection of input parameters and a representative training data set are crucial for the success of any method. The quality of the used DTM is clearly visible in the final output map. Although the difference in the overall statistics is only moderate, it is preferable to use the DTM with the highest resolution available in order to pinpoint the hazard areas in detail. For remote areas with a lack of detailed data, multi image matching of satellite scenes is a possibility to obtain a DTM suitable for landslide susceptibility analysis restricted to non vegetated areas. For data visualization, the selection of a DTM depends of the application, aims and the thematic detail, which should be visualised.

REFERENCES

BEV (Bundesamt für Eich- und Vermessungswesen). 2007. Produktinformation Digitales Geländehöhenmodell. Available at: http://www.austrianmap.at/bevportal/Produkte/pdf/dgm-hr.pdf [accessed May 2007].

Bonham-Carter, G.F., Agterberg, F.P. & Wright, D.F. 1988. Integration of geological datasets for gold exploration in Nova Scotia: *In Photogrammetric Engineering and Remote Sensing* 54 (11) 1585–1592.

Granica, K., Almer, A., Hirschmugl, M., Proske, H., Wurm, M., Schnabel, Th., Kenyi, L.W. & Schardt, M. 2007. Generation and webGIS representation of landslide susceptibility maps using VHR satellite data. To be published in: *Proceedings of IGARSS2007*, Barcelona, July, 23rd–27th 2007.

Hansen, M. J. 1984. Strategies for classification of landslides. In: Slope Instability. D. Brunsden and D. B. Prior (Eds.), Wiley & Sons, New York, pp. 1–25.

McKean, J., Roering, J. 2004. Objective landslide detection and surface morphology mapping using high-resolution airborne laser altimetry. *Geomorphology* 57: 331–351.

Raggam, J., Wack, R. & Gutjahr, K.H. 2007. Mapping capability of a low-cost aerial data acquisition platform – first results. *ISPRS Hannover Workshop 2007*, "*High-Resolution Imaging for Geospatial Information*", May 29–June 1, 2007. To be published.

Sawatzky, D.L., Raines, G.L., Bonham-Carter, G.F. & Looney, C.G. 2004. ArcSDM2: ArcMAP extension for spatial data modelling using weights of evidence, logistic regression, fuzzy logic and neural network analysis. http://www.ige.unicamp.br/sdm/ArcSDM2.

Van Westen, C.J. 1993. Training package for geographic information systems in slope instability zonation. Vol. 1: Theory: Application of geographic information systems to landslide hazard zonation. ITC publication No. 15, International Institute for Aerospace Survey and Earth Sciences, Enschede, The Netherlands.

Wack, R., Wimmer, A. 2002. Digital Terrain Models from Airborne Laserscanner Data – a Grid based approach. *Proceedings of the ISPRS Commission III Symposium Graz,* pp. 293–296.

WebTerrainServer. 2007. http://portal.opengeospatial.org/files/?artifact_id = 1072 [accessed: May 2007].

Web 3D Service. 2007. https://portal.opengeospatial.org/files/?artifact_id=8869 [accessed May 2007].

Weirich, F., Blesius, L. 2006. Comparison of Satellite and Air Photo Based Landslide Susceptibility Maps. Artical in press: doi:10.1016/j.geomorph.2006.10.003.

WMS 2007. http://portal.opengeospatial.org/files/?artifact_id=16075 [accessed: May 2007].