The Avalanche Geodatabase Development and Hazard Mapping for the Bishkek-Osh Road in Kyrgyzstan

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Abstract
About 53 % (105 000 km²) of the territory of the Kyrgyz Republic are subject to avalanche activity. It is estimated that there are about 30 000 avalanche release areas, from which about 1 000 (3 %) pose a serious threat to people. However, due to new developments in the mountains (e.g. new roads) it is likely that the risk will increase in the next years. The main objective of this research was development of the digital avalanche geodatabase with hazard mapping and modelling of the afforestation susceptibility along the M41 Bishkek-Osh Road. It is the main road between the two largest cities of the Kyrgyz Republic, Bishkek and Osh. The highway crosses the Kyrgyz Range, the Talas Range and the Fergana Range of the Tian Shan Mountains and passes through regions with hot or warm summers, with cool summers and cold winters, through cold steppe and, in the high altitudes, through tundra climates. Various natural hazards endanger the mountainous sections of the highway including the avalanche hazard. The road section from the Ala-Bel Pass to Toktogul Town is selected for the identification and detailed analysis of the avalanche prone areas with the highest potential for reforestation and afforestation. This study included the delineation of the exact release areas as polygon based on an analysis of the inclination, surface roughness and flow accumulation. The release areas are linked to the avalanche catchments in the avalanche cadastre and can in future be used to simulate the runout distance and the destructive potential of design avalanches. The further modelling and mapping of the basic avalanche initiation susceptibility resulted in a map of potential avalanche release areas and the release susceptibility. The GIS based avalanche cadaster only contains large avalanche catchments, which pose a known and considerable risk to the road and mainly originate from avalanche release areas situated above the current mean or upper timberline. This study is part of the project "Natural Hazard Risk Management for Transport Infrastructure in Kyrgyzstan: Focus Avalanche Protection Forests" funded by the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW).

1. Introduction

Avalanche damage to transportation infrastructure, communication and power lines, forestry, industry and housings are reported every year in Kyrgyz Republic (Ivanova et al., 2012). In addition to direct damages, economic losses due to frequent road closures are high. During one winter season about 800 to 1500 avalanches are registered in Kyrgyz Republic; however, these numbers are only a small percentage of the actual avalanche activity. The avalanche period lasts for 3-4 month in the Western Tian Shan and 11-12 month in the Central Tian Shan. The 233 reported avalanche fatalities (1936-2012) are divided as follows:

- 38 % (94) climbers, skiers;
- 30% (63) residents of the settlements;
- 13 % (33) drivers and passengers;
- 19% (43) shepherds, hunters, geologists, workers.

The forest in the Kyrgyz Republic has been negatively affected by the political and economic conditions over the past decades. Mitigation by protection forests is an unknown concept to natural hazard as well as forest experts in the Kyrgyz Republic and is not part of sectorial laws and regulations. In regard to the Kyrgyz government's commitment to increase the percentage of forests from about 7 % to 11 %, it would be a good opportunity to consider mitigation against natural hazards as a forest function and support the afforestation in endangered areas. The research has introduced the concept for avalanche protection forests, however, in the Kyrgyz Republic the afforestation may have a greater impact on reducing the risk of landslides and soil erosion.

The Kyrgyz Republic is a mountainous country, as about 90 % of its total area (198500 km²) is located above 1500 m a.s.l. and approximately 50 %

above 3000 m a.s.l. (Scheuber et al., 2000). The climate is dry continental, however, the yearly precipitation ranges from 90 mm in the east of Tian Shan to 1000 mm in the south-west region of the Fergana Mountains (Scheuber et al., 2000). According to Chyngojoev et al., (2010) the forested areas (forests and shrubs) of the Kyrgyz Republic amounts to 1123200 ha, which corresponds to about 6 % of the total area of the country. Even though the forest cover is small in size, it still serves as protection against rockfall and avalanches (DEZA, 2009). Considering only terrain criteria, according to first rough estimations 65 % of the area is prone to avalanches (Ivanova et al., 2012). The two largest cities, Bishkek and Osh, are home to 80 % of the country’s industry (KRI, 2008). Figure 1 shows the main road between the two cities, which has a high strategic importance. Various natural hazard processes endanger the road and a permanent safe accessibility cannot be guaranteed without further mitigation and adaptation by sustainable planning.

The main objective of the project was to contribute to a sustainable natural hazard management along transportation corridors in the Kyrgyz Republic by introducing the digital avalanche cadastre, an hazard map (Ala-Bel Region), a map of the current protection effect, an afforestation susceptibility model and a map of potential protection forests. The main outcome, regarding avalanche hazards is a digital avalanche cadastre, which is already in use at the Ministry of Emergency Situations of the Kyrgyz Republic (MES). It includes the outlines of avalanche catchments and information on the geomorphology, vegetation, soil, frequency of artillery control and the hazard potential – to name a few. The hazard map comprises additional information on the exact release areas per catchment and an estimation of the runout length. This leads to an estimation whether it is likely that the road is impacted.

The identification of the avalanche protection forest and the afforestation suitability was performed on a regional and a local scale. The regional approach aimed at the identification of areas best suited for forest growth. For this we analyzed climatic ecoregions for the transection along the Bishkek-Osh Road based on own observations as well as on precipitation, geographical, forest and growth information available in the literature. This resulted in maps of the climatic forest growth potential for the entire region along the highway. The further modelling and mapping of the basic avalanche initiation susceptibility resulted in a map of potential avalanche release areas and the release susceptibility.

For the detailed analysis on local scale, we selected the road section from the Ala-Bel Pass to Toktogul, because here we expect the highest potential for reforestation and afforestation. This study included the delineation of the exact release areas as polygon based on an analysis of the inclination, surface roughness and flow accumulation. The release areas are linked to the avalanche catchments in the avalanche cadastre and can in future be used to simulate the runout distance and the destructive potential of design avalanches.

2. Data and Methodology

2.1 Digital Elevation Model (DEM)

As no national high-resolution DEM data is available in the Kyrgyz Republic, we acquired free satellite data, namely ASTER and SRTM datasets. The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is an imaging instrument onboard Terra, the flagship satellite of NASA's Earth Observing System (EOS) launched in December 1999 (http://asterweb.jpl.nasa.gov). NASA has made a DEM available, which is based on ASTER data (GDEM). NASA's Shuttle Radar Topography Mission (SRTM) acquired the SRTM data. Both DEM are available in 30 m GSD. Generally, the higher the GSD, the more accurate the DEM represents the true terrain morphology. However, a comparison revealed that ASTER has less data gaps and therefore we used this DEM for further analysis. Other data with a higher GSD are available, but are costly. The use of a 30 m model in our work was challenging as the spatial analysis of terrain features may introduce smoother terrain and therefore it is difficult to delineate release areas and estimate the run-out length of avalanches.

2.2 Aerial Imagery

Natural hazard and forest mapping requires aerial or satellite imagery of sufficient spatial resolution and quality. However, national aerial VHR imagery is not available for Kyrgyz Republic. Hence, we used Google Earth, Bing maps and ESRI's World imagery available via GIS-Software plugins and WMS functionalities as base maps. These services provide imagery from different sources, resolution and data, but homogenous HR imagery covers the area of in-depth hazard analysis (Figure 2).

2.3 Thematic Maps

The topographic, forestry, soil and road infrastructure maps have been received from the government agencies and research institutions. These paper based maps are scanned, georeferenced and digitized as vector layers for the avalanche geodatabase.

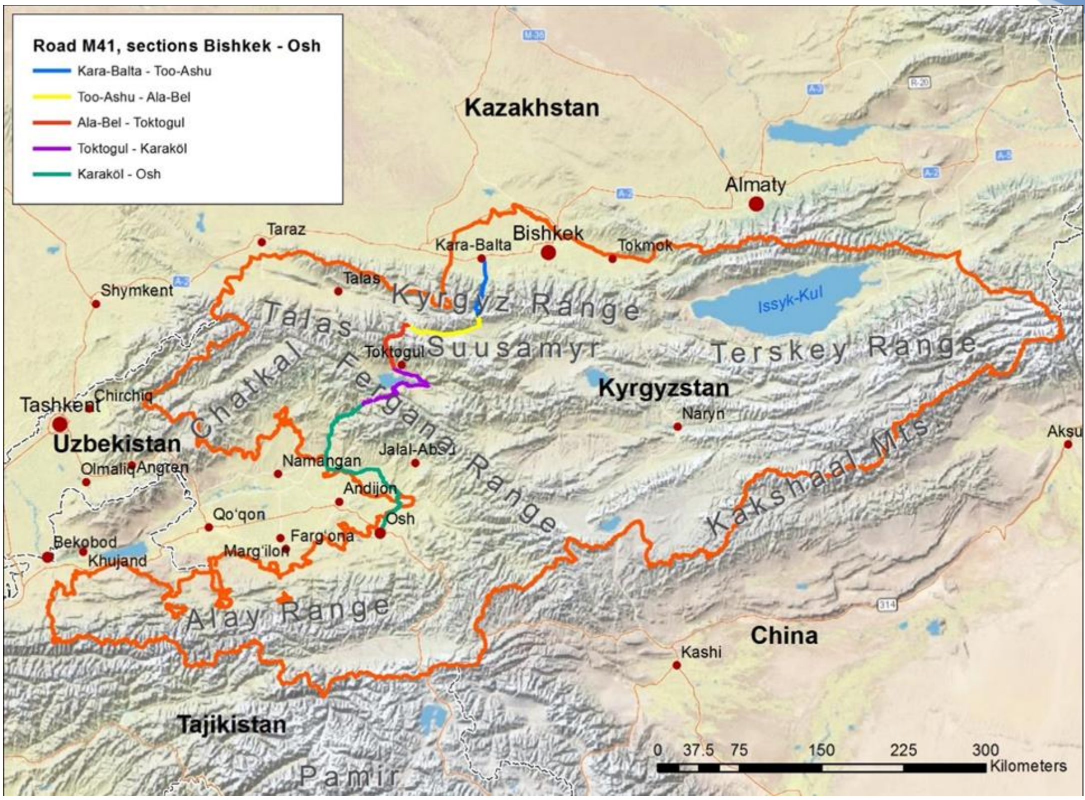

Figure 1: The Route M41 between Bishkek and Osh crosses the Tian Shan Mountains

Figure 2: Avalanche depositions visible on Bing Aerial

2.4 Hydro-Meteorological Datasets

The topographic, forestry, soil and road infrastructure maps have been received from the government agencies and research institutions. These paper based maps are scanned, georeferenced and digitized as map layers of the avalanche geodatabase.

2.5 Avalanche Information

The main source of information for avalanche hazard and protection forest mapping is the avalanche cadastre of Ministry of Emergency Situations of the Kyrgyz Republic (MES) consisting of avalanche release area maps (Figure 3) and so called avalanche passports. On base of theses information the digital avalanche cadastre is developed.

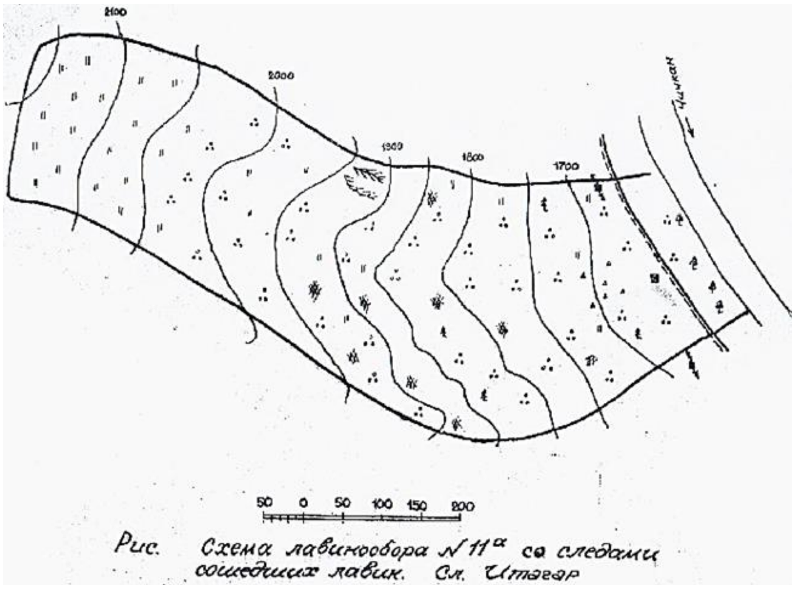

Figure 3: Avalanche release area map

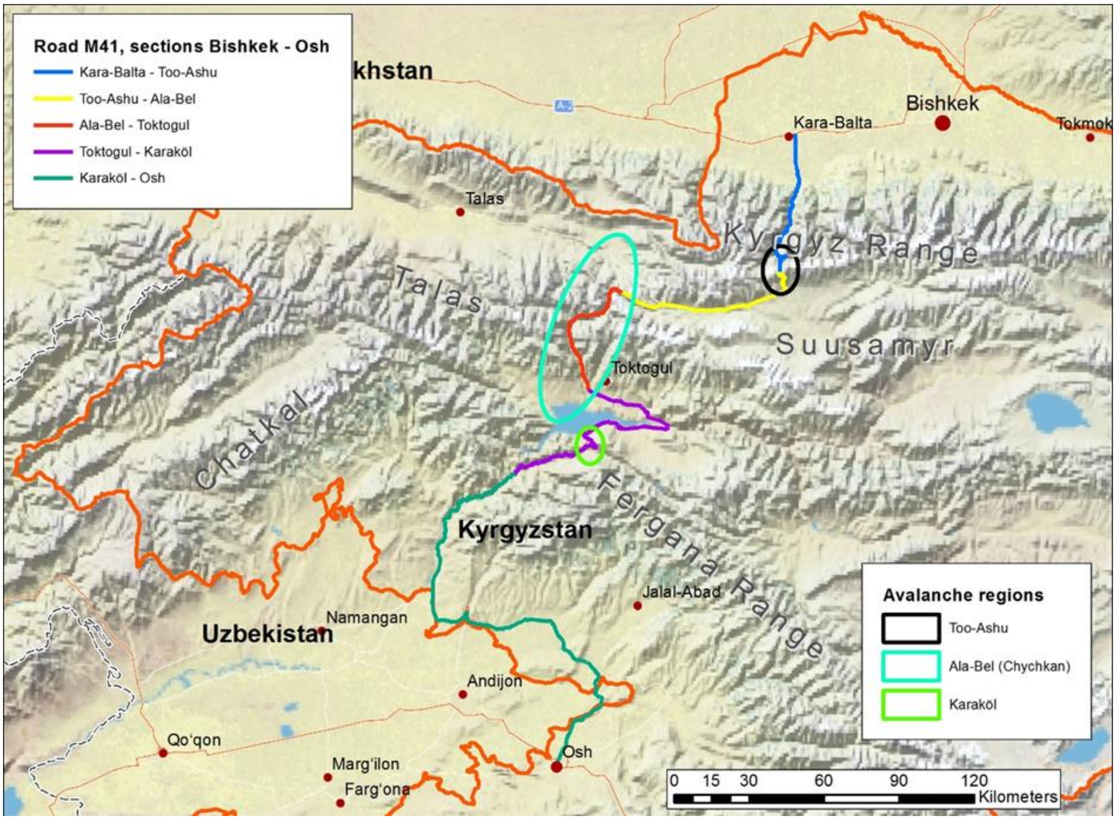

Figure 4: The avalanche endangered road sections of the Route M41

3. Development of a Digital Avalanche Cadastre

The Ministry of Emergency Situations (MES) and The Ministry of Transport and Roads (MTR) of the Kyrgyz Republic are responsible for the mitigation of avalanche hazards along transportation corridors. Figure 3 is an overview of the locations of endangered road sections. In the frame of the project the digital avalanche cadastre for the Too-Ashu and the Ala-Bel avalanche regions have been created, other regions shall be included in the next years. Up to now most of the data were only available on paper and were not processed for further use in hazard and risk assessments. Therefore, AvaProForest was an opportunity to establish a digital avalanche cadastre for operational use in the Kyrgyz Republic. Anyhow, the final verification with MES experts has not been completed and we strongly encourage the experts to do so even after the project ended. MES provided paper maps of avalanche catchments for three main avalanche hazard regions along the M41, the Too-Ashu, the Ala-Bel (Chychkan) and the Karaköl avalanche observation sections (Figure 4).

In addition, MES provided information about the avalanche hazard characteristics such as how many release areas are in one catchment, how often the specific catchment is mitigated using artillery and whether the avalanche pose a risk to the road or not. However, the digitized information does not yet include information on avalanche events, which would allow statistical analysis. The data are stored in the archives of MES, and it is a goal to digitize the information for future hazard and risk assessments. The avalanche hazard areas were only available on paper maps. The maps had to be scanned and georeferenced. Then map contents are digitized into vector format. This was a challenging task as it was difficult to locate the correct catchment areas based on drawings as shown in Figure 3.

The avalanche cadastre (AcaCadastre) now comprises a Geodatabase and includes the results from the hazard mapping. The database contains the information provided by the avalanche experts of MES and the Austrian Federal Research Centre for Forests, Department of Natural Hazards (BFW) and is in use in daily decision-making. The main database is in Russian so that the local experts and MES can use the database for their work. It is expected that the new Geodatabase elaborated during the project will be a significant contribution to further activities of the Kyrgyz state agencies and international institutions on reduction of disaster risk to transport corridors in mountainous regions of the Kyrgyz Republic by applying the existing Kyrgyz experience and new technologies of hazard analysis and protection forest management from Austria.

4. Regional Scale Mapping of the Basic Avalanche Initiation Susceptibility

In order to identify areas, where forests could be able to protect infrastructures like the Bishkek – Osh road M41, it is necessary to map the potential avalanche hazard zones, which may affect the objects of interest (hazard indication mapping) (Perzl et al., 2012). The first step of this task is the mapping of the potential avalanche release areas (PRA, Gruber 2001 and Maggioni et al., 2002) and their basic avalanche initiation susceptibility (BAIS). The BAIS characterizes the probability of snow avalanche formation. This probability depends on climatic and topographic characteristics. The BAIS does not consider the protective effect of forest. Consideration of the forest effects is a part of the hazard mapping on local scale. Zyskova (2007) has done a first large scale modelling of the potential avalanche release zones of the Kyrgyz Republic. Snow depth, the steepness and the roughness of the terrain determine the probability of snow avalanche formation on a given slope (Schaerer, 1981 and Severskiy and Blagoveshchenskiy, 1996).

According to observations from Ma and Hu (1990), avalanches occur frequently in the Chinese Tian Shan Mountains at a total snowpack height of more than 50 cm. Hu et al., (1992) and Blagovechshenskiy et al., (2004) specified a critical minimum full snow depth for avalanche release of 25 to 30 cm in the Eastern (Chinese) and Northern (Kazakh) Tian Shan Mountains. That corresponds to the descriptions of the avalanche observers at Too-Ashu and Ala-Bel Pass. In the Chinese (Hu et al., 1992) and the Zailiyskiy Ranges of the Tian Shan Mountains (Blagovechshenskiy et al., 2008) large avalanches were usually observed when snow depth exceeds 70 cm. However, there is a relationship between snowpack conditions and slope gradients providing an avalanche initiation (Perzl et al., 2014).

5. Avalanche Hazard Susceptibility Mapping

We analysed the avalanche hazard susceptibility the observed avalanche activity and the afforestation susceptibility along the Route M41 from Kara-Balta to Osh taking into account landuse and technical constraints of afforestation (e.g., site accessibility). Notice that the avalanche hazard susceptibility is not the same as the avalanche hazard risk. The hazard susceptibility results from the release probability (BAIS) and the potential intensity of the avalanche impact on infrastructures to be protected. The avalanche hazard susceptibility does not consider the protective effect of forests and defense constructions. The hazard susceptibility also does not consider the vulnerability of the infrastructure. However, risk assessment requires in-depth analysis on local scale additionally. Risk assessment is purposive only, if there is an evidence of hazard susceptibility (Figure 5). The avalanche hazard is not acceptable, if an avalanche, starting from parts of the potential main release areas (PMRA) without a full protective forest cover, may reach the infrastructure.

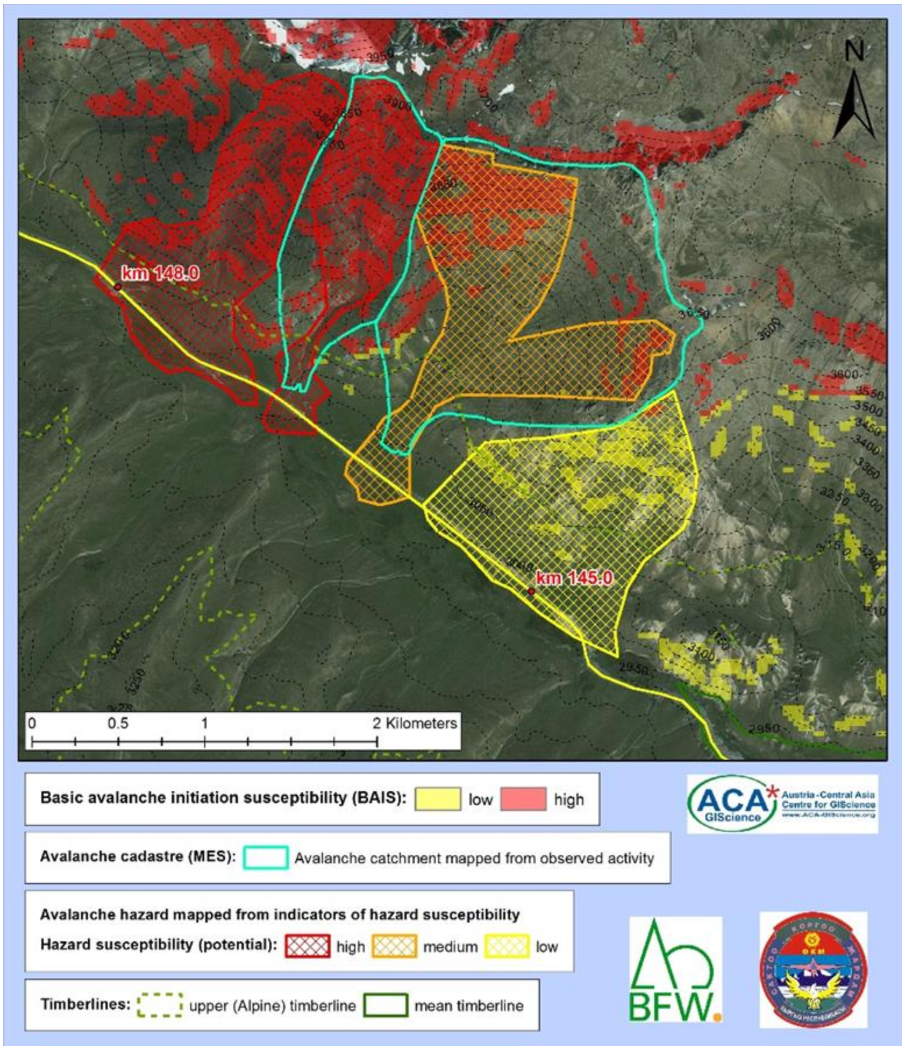

Figure 5: Avalanche risk map based on BFW and MES assessment

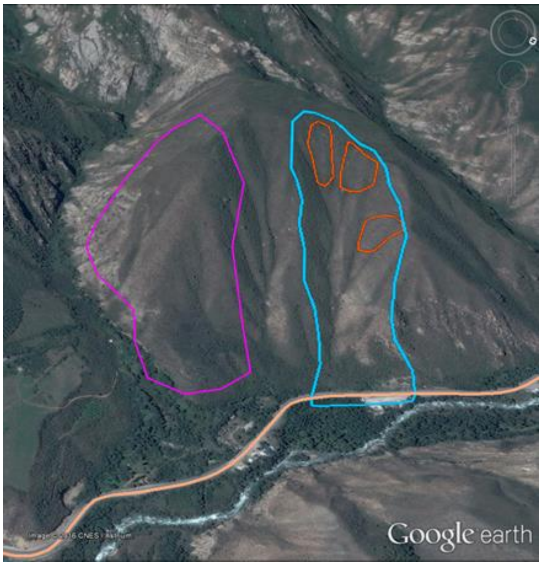

Figure 6: Hazard mapping on local scale: Verification and adaption of the catchments in the cadastre (pink), blue are the final catchments with the hazard line close to the road and the main release areas (orange)

In order to provide some form of hazard mapping, we defined a hazard line, which indicates how far one might reasonably expect avalanches to run (McClung and Schaerer, 2006). Because we do not have any frequency data, we draw the line as a potential runout line, which closes the avalanche catchment based on descriptions of local avalanche observers, expertise and basic calculations, including the energy line concept. The following three scenarios are possible:

1) the line goes beyond the road: both, the dense flow and the powder part of an avalanche may reach the road
2) the line reaches the road: it is likely that only the powder part of an avalanche reaches the road
3) the line ends before the road: it is unlikely that the avalanche reaches the road.

Especially in regions with a highly fragmented forest cover, the mapping of forests and their protective effects is very laborious. Hence, in relation to hazard mapping, it is recommended to map the PMRAs first, and then to limit the delineation of forest units to PMRAs or avalanche catchments. In regions with a low forest percentage, it is more efficient to map wooded land providing a sufficient protection than to delineate forest areas with no sufficient effect. We only mapped stockings providing a sufficient protection within the avalanche catchments according to the verified avalanche cadastre on base of aerial imagery. However, we also enclosed such stockings out of the hazard zones according to the cadastre, if our modelling of the BAIS and expert opinion indicates an avalanche damage potential for the M41.

6. Verification of Avalanche Catchments and Delineation of Avalanche Release Areas

The digital avalanche cadastre includes the shapes of the known avalanche catchments, which mark the most dangerous avalanche sites along the Toktogul - Ala-Bel section of the road. Also included in the cadastre are information on the number of the release areas in one catchment that may have the potential to reach the road. The first step was to verify the avalanche catchment extent. During our field trip, we discussed the entries in the cadastre with the local experts from MES and took photographs. Based on data from ArcGIS and Google Earth we adapted the initial catchments and relocated some of them. Special attention was paid to the catchment's correct location and boundaries. Figure 6 shows this verification process, where the pink catchment is the original line and the blue line represents the final catchment boundary as verified by the experts. Then, we delineated the potential release areas (PRAs) as polygons. These release areas can be used to assess the release volume of possible avalanches (giving an indication on the avalanche's intensity and destructive potential), identify the best target point for artillery control, as an input for runout simulation models and to identify the likely path and runout distance.

For the delineation of PRAs, we used a simple topographical analysis based on the slope angle and the flow accumulation similar to PRA (BAIS) mapping on regional scale. With higher resolution DEM and a better knowledge of the avalanche, climatology and snow condition, it is usual to run an automated GIS analysis based on e.g. the slope angle, the curvature, the wind direction, exposition. The release areas are the potential without consideration of forests and without information on the release volume or the type of avalanche and frequency. On the aerial imagery it was possible to exclude rocky terrain from the release areas and also to better identify smaller ridges that did not show up on the analysis of the 30 m DEM. Figure 6 also includes three release areas that we delineated by applying a standard spatial analysis procedure.

For the 54 known avalanche catchments, we delineated 170 potential main release areas (PMRA) and 39 secondary release areas (PSRA) with an area of 624.9 ha. The PSRAs are not likely to reach the road, in case that the release on their own. However, they may be a source of snow entrainment.

7. Conclusion

With regard to avalanche risk management within the project AvaProForest we were able to start building-up a structured documentation platform with the digital avalanche cadaster and the hazard map. Both are in-use operationally at the Ministry of Emergency Situation (MES). Anyhow, it was only possible in the frame of the project to deliver preliminary results that are the basis for future risk management consideration (e.g. avalanche warnings, spatial planning, planning of mitigation measures). On the example of one study region, we were able to develop and apply a methodology that meets the Kyrgyz requirements and considers the limited data availability. Improvements directly regarding the cadastre and the avalanche hazard map include:

1. Verification of the delineated avalanche release areas and avalanche catchments in the project AvaProForest;
2. Complete the hazard assessment for road section, in the current map classified as "not

assessed”. This includes smaller avalanches and snow gliding processes in areas with a higher afforestation potential than in the release areas of larger avalanches;

3. Enlargement of the study areas. The hazard map is only available for the focus area: road section between Ala-Bel Pass and Toktogul;
4. Link the digital avalanche cadastre to an event database (requires the digitalization of the event documentation that is only available on paper);
5. Develop courses for educating a) natural hazard practitioners and b) academics;
6. Geodatabase implementation.

Improvements with a wider scope include:

1. Inclusion of other natural hazard process, e.g. rock fall, debris flow, shallow landslides;
2. Consider other endangered areas in the Kyrgyz Republic;
3. Foster an inter-sectoral and cross-level natural hazard management processes. E.g. for an effective hazard management representatives from municipalities, land use offices, critical infrastructures and emergency organization should be involved in the risk management cycle;
4. Define protection goals for settlement and non-settlement areas and develop recommendations on how to assess the risk. Up to now, the availability of basic data for an appraisal is limited;
5. Implement aspects of integral risk management structure in the legal system.

Acknowledgement

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References

Blagovechshenskiy, V., Gulyaeva, T. S. and Kokarev, A. L., 2004, Natural Hatards Estimation and Mapping in the Dzungar Alatau Range (Kazakhstan). *Internationales Symposion INTERPRAEVENT 2004 – Riva/Trient, Tagungspublikation*, Band I: 27-35

Blagovechshenskiy, V., Egorov, A. and Kokarev, K., 2008, Avalanche Activity and Avalanche Risk in the Zailiyskiy Alatau Range (Kazakhstan). *INTERPRAEVENT 2008*, Extended Abstracts: 50-51.

Chyngojoev, A., Surappaeva, B. and Altrell, D., 2010, Capacity Building for National Forest and Tree Resource Assessment and Monitoring Project and Contains Statistical Data on the Analysis and Evaluation of the Forest and Tree Resources of Kyrgyz Republic. FAO TCP/KYR/3102, Bishkek.

DEZA, 2009, Nachhaltig bewirtschafteter Wald bringt Auskommen und Zukunft – ein DEZA Projekt weist den Weg. Central Asia Briefing.

Gruber, U., 2001, Using GIS for Avalanche Hazard Mapping in Switzerland. *Proceedings of the 2001 ESRI International User Conference*, July 9-13, 2001, San Diego.

Hu, R., Ma, H. and Wang, G., 1992, An Outline of Avalanches in the Tien Shan Mountains. *Annals of Glaciology*, Vol. 16, 7-10.

Ivanova, I., Frolova, G. and Zyskova, S., 2012, Identification of Potential Avalanching Zones in Kyrgyz Republic Using RS Data and GIS Technologies. *Oral Presentation at the 32nd EARSeL Symposium and 36th General Assembly*, Greece.

KRI International Crp., 2008, Bishkek-Osh Road Rehabilitation Projects. Retrieved on February 19th, 2013: *www2.jica.go.jp/en/.../pdf/2008_K-YR-P2_4.pdf.*

Ma, W. and Hu, R., 1990, Relationship between the Development of Depth Hoar and Avalanche Release in the Tian Shan mountain, China. *Journal of Glaciology*, Vol. 36, 122, 37-40.

Maggioni, M. and Gruber, U., 2002, Definition and Characterisation of Potential Avalanche Release Areas. *Proceedings of the 2002 ESRJ International User Conference* July8-I2, 2002, San Diego.

McClung, D. and Schaerer, P., 2006, *The Avalanche Handbook*. Seattle, USA.

Perzl, F., Walter, W., Zeidler, A. and Adams, M., 2012, Assessment of the Avalanche Impact on Transportation Infrastructure (Act. 5.4). Report on the Identification of Snow Avalanche-Endangered Road Sections in the Stanzer Valley (AT). Alpine Space Program. Paramount Project Deliverables. BFW, Innsbruck.

Perzl, F., Huber, A. and Fromm, R., 2014, GRAVIPROFOR. Verbesserung der Erfassung der Schutzwaldkulisse für die forstliche Raumplanung. Methodik - Prozessmodellierung Schneelawine. Technische Hilfe im Rahmen des österreichischen Programms LE 07-13.

Projektbericht, Projekt Teilbericht im Auftrag des BMLFUW. Bundesforschungszentrum für Wald (BFW), Innsbruck.

Schaerer, P. A., 1981, Avalanches. In: Gray, D.M. & Male, D.H. (1981): Handbook of snow. Principles, Management & Use. Blackburn Press. Caldwell, New Jersey.

Scheuber, M., Müller, U.; and Köhl, M., 2000, Wald und Forstwirtschaft Kirgistans. *Schweiz. Z. Forstwes*. Vol. 151(3): 69-74.

Severskiy, I. and Blagoveshchenskiy, V., 1996, The Estimation of Avalanche Hazard of Mountain Territories. *Internationales Symposion INTERPRAEVENT 1996 – Garmisch-Partenkirchen*, Tagungspublikation, Band 2: 91-101.

Zyskova, S., 2007, Identification of Potential Avalanching Zones in Kyrgyz Republic using RS Data and GIS-Technologies. *Centre for Space Science and Technology Education in Asia and Pacific*, Dehradun, India.

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