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A REGIONAL SCALE RISK ANALYSIS IN THE COMMUNITY OF ÓLAFSFJÖRÐUR, ICELAND

EINE REGIONALE RISIKOANALYSE IN DER GEMEINDE ÓLAFSFJÖRÐUR, ISLAND

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ABSTRACT

This study focuses on the conceptual approach to natural hazard investigations in regions lacking hazard zoning or where only rudimentary hazard assessments exist. The Icelandic sample area of Ólafsfjörður is located in a high mountain environment in northern Iceland. It is subject to frequent processes such as snow avalanches, debris flows and rock fall. The objective of this procedure is to identify the risk potential on a regional scale. The first step is hazard process identification, followed by the application of GIS-based avalanche and rock fall simulation models in a worst-case scenario. Next, the damage potential, representing objects of human interest, is acquired. In a final step the spatial extents of hazard processes and human settlements are overlapped allowing an overview of potential zones of conflict. The results reveal that a considerable number of objects are located within potential avalanche runout. This concept allows the areas of conflict to be quickly obtained while forming the foundation for further detailed studies.

ZUSAMMENFASSUNG:

Diese Untersuchung stellt eine konzeptionelle Methode zur Untersuchung von Naturgefahren in Regionen ohne existierenden Gefahrenzonen oder wo es nur eine rudimentäre Gefahrenbeurteilung gibt, dar. Das isländische Testgebiet Ólafsfjörður befindet sich in einem Hochgebirgsraum in Nordisland und unterliegt den Prozessbereichen Lawinen, Muren und Steinschlag. Das Ziel dieser Untersuchung ist die Identifizierung des Risikopotentials im regionalen Maßstab. In einem ersten Schritt sollen die vorkommenden Gefahrenprozesse identifiziert werden. Anschließend erfolgt die Anwendung von GIS-basierten Lawinen- und Steinschlag Modellen um ein ‚Worst-Case-Szenario' darzustellen, gefolgt von der Ermittlung des Schadenpotentials, das aus Objekten gesellschaftlicher Interesse besteht. In einem letzten Arbeitsschritt werden die räumlichen Ausdehnungen der Gefahrenprozesse mit den Siedlungsräumen verschnitten um die potentiellen Konfliktzonen zu ermitteln. Die Ergebnisse zeigen, dass sich eine beachtliche Anzahl der Objekte innerhalb der potentiellen Lawinenreichweite befinden. Dieses Konzept ermöglicht, die schnelle Ermittlung von Konfliktzonen, die wiederum die Grundlage für weitere detaillierte Untersuchungen bilden.

Key words: Risk analysis, regional scale, Iceland

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1. MOUNTAIN HAZARDS IN ICELAND

Iceland, an island in the North Atlantic about 103,000 km² in size, is characterized by several vast mountain regions. These areas are regularly subject to a multitude of gravity-driven slope processes such as snow avalanches, landslides, debris flows and rock falls. Dealing with these processes is of great importance for the inhabitants of the various mountain areas. While the rural population of Iceland is currently experiencing a general decrease, it is a concern of the government to support the peripheral communities (JÓHANNESSON 2000). Consequently, to prevent further population decreases, various means of making these areas more attractive for the local population are necessary. In order to counteract this trend on a long term scale, it will be necessary to make appropriate economic investments, which only make sense in low risk environments. Therefore, the long term persistence of villages in Iceland is closely coupled to succeeding in minimizing risks within the coming years.

The long history of natural hazard events in Iceland reaches back as far as the settlement of Iceland in ninth century AD (BERGÞÓRSSON et al. 1988). Various reports can be found in annals, sagas and other sources and have been gathered and summarized, among others, by BJÖRNSSON (1980), PÉTURSSON (1991), PÉTURSSON (1992), JÓNSSON & PÉTURSSON (1992), PÉTURSSON (1996), PÉTURSSON & JÓNSDÓTTIR (2000), PÉTURSSON & JÓNSSON (2001) and JÓHANNESSON & ARNALDS (2001). Until the nineteenth century AD, the entire Icelandic population was rural, living on individual and often isolated farms, meaning that in the case of a natural hazard event, generally only few people were affected per incident. In this first time period lasting approximately to the year 1900, a total of 487 victims of snow avalanches and other mountain hazards were recorded (BJÖRNSSON 1980). From the second half of the nineteenth century onwards, several major snow avalanche events have occurred in various fishing villages. According to JÓHANNESSON & ARNALDS (2001), in the 20th century AD, a total of 193 people died in Iceland largely due to snow avalanches. Of these, some 113 were either in buildings or within urban areas.

Two catastrophic avalanche events in 1995 began to raise questions concerning avalanche protection measures and the future probability of such incidents. The first took place on January 16, 1995 in the fishing village of Suðavík. In this accident, 14 of the 230 inhabitants lost their lives when an avalanche moved beyond the avalanche hazard zone of that time, striking 17 buildings, of which 14 had been previously thought to be in a safe zone (EGILSSON 1996). The western fjords were struck again by another fatal snow avalanche only 10 months later. On October 24, in the town of Flateyri, with a population of 379 inhabitants, 20 people were killed in a snow avalanche. In this case, only three of the destroyed houses were located in the avalanche hazard zone of that time, while 26 of the destroyed buildings were situated beyond any area perceived to be endangered. Since then a paradigm shift has taken place in Iceland concerning matters such as risk tolerance and risk concepts. Efforts to minimize potential risk have been conducted in manifold ways, e.g. in terms of organization and by strengthening already existing institutions (e.g. IMO, Icelandic Meteorological Office), creating new structures, improving various temporary protection measures and constructing permanent defense measures (HARALDSDÓTTIR 1998). However, still in an initial stage, not all potentially endangered mountain communities in Iceland have been subject to a comprehensive hazard assessment.

Ólafsfjörður, location and past events

Ólafsfjörður is a small community still lacking a comprehensive hazard assessment. With its 1,100 inhabitants, it represents an ordinary Icelandic coastal settlement with many common natural characteristics as well as problems, trends and chances. Thus the community of Ólafsfjörður is an ideal test area for the initial application of this concept in Iceland. Moreover, Ólafsfjörður has been placed on the list of critical towns by the IMO, which is responsible for dealing with gravity-forced hazard processes (JÓHANNESSON & ARNALDS 2001). While its recent history is nearly void of fatal accidents in regard to natural hazards, records of various incidents are known to have taken place in the past within the study area (Fig. 1).

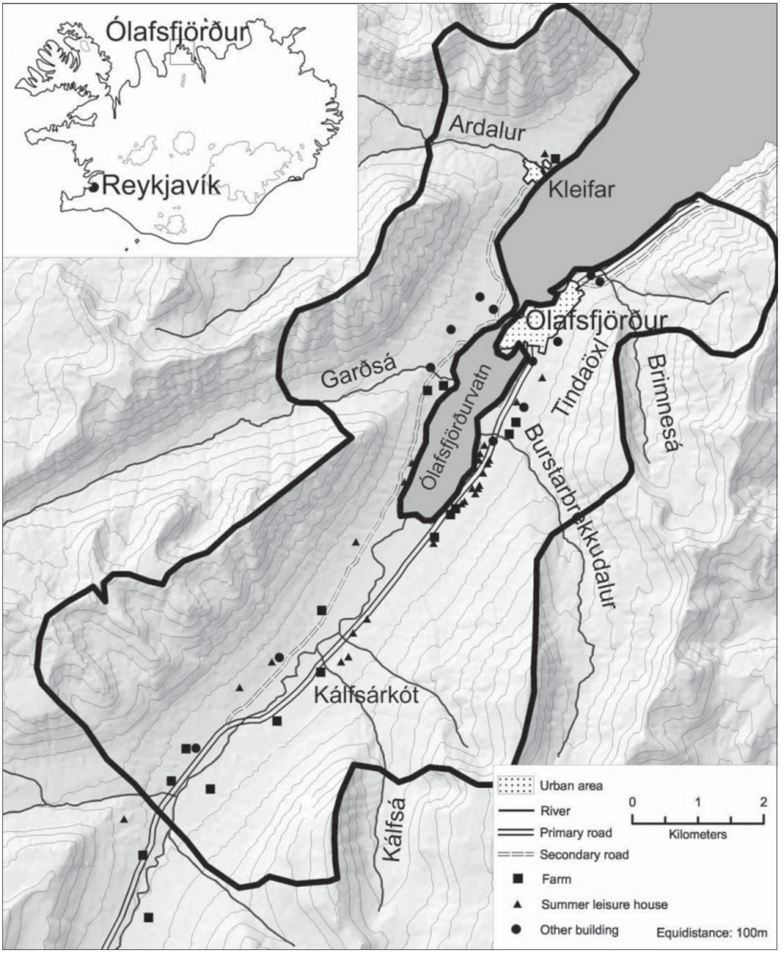

Fig. 1: Study area of Ólafsfjörður.
Abb. 1: Untersuchungsgebiet Ólafsfjörður

The region of Ólafsfjörður is regularly affected by snow avalanche processes. While most of the occurrences generally remain far enough away from populated areas, avalanches do regularly reach valley regions. In these cases, transportation routes and housing areas can be endangered. Exact descriptions of avalanche events are sparse in regard to locations, runout distances, avalanche types, trigger zones etc, as a systematic avalanche register is non existent in the region. However, more snow avalanche occurrences are known for the western part of the study area. The reasons for this distribution are manifold. The dominating wind direction from the northwest results in an intensified snow accumulation on the lee side. The exposure to direct radiation favors the formation of wet snow avalanches and the topographical features of the mountains on the western side, marked by many small cirques, additionally encourage intensified snow accumulation and thus the formation of considerable sized avalanches. Therefore, every cirque serves as a potential avalanche starting zone. In the north avalanches reach the sea, and the western mountain ranges represent a severely avalanche prone region, with snow avalanches regularly reaching the lake in the north and the valley floor further south. Snow avalanches are known to have twice destroyed a summer cottage on the west side of the valley across from Kálfsárkot, which has been rebuilt yet another time at the same location (Eðvaldsson, personal communication 2002). A reason for the significantly lower avalanche activity in the eastern part of the study area lies e.g. in the windward direction, which allows snow to be blown away easily. Another factor for the lack of avalanches there is the lower hillslope gradients in the starting zones, permitting the triggering of avalanches only under extreme circumstances. In contrast, the Tindaöxl has experienced several avalanches, of which one avalanche reached the area just above of the uppermost houses of Ólafsfjörður in 1952 (JÓHANNESSON & SÆMUNDSSON 1997).

Apart from snow avalanche activity, the region has a history of debris- and mudflows. For example, on August 28, after a period of heavy precipitation, Ólafsfjörður was struck by two mudflows that were triggered on the lower Tindaöxl slope above the town, while a series of other small debris- and mudflows in the region followed. The consistency of the mudflows was characterized by a saturated, low viscous, liquefied mud mass. This was a type of fine granular flow, consisting of a high liquid content and solid particles of small grain sizes ranging from small rocks to fine clay. The impact moved larger rocks and boulders lying in the path and dislodged rocks embedded in the surface substratum and underlying matrix. These mass movements were marked by a rapid flow velocity, easily able to sweep away automobiles. Together both mudflows had a width of around 150 meters (PÉTURSSON 1991, OLGEIRSON 1991). The starting zones of all these mudflows were around the elevation of about 150 meters a.s.l. Several houses located on the lower slopes of the town were hit in this incidence, causing serious damage, but no human casualties were registered.

2. THE CONCEPT OF A REGIONAL SCALE RISK ANALYSIS

The concept applied in this study is based on the risk analysis according to HEINIMANN et al. (1998). Since natural processes, such as snow avalanches or debris flows, are only considered natural hazards when coming into contact with human assets, or when posing a threat to human lives, the investigation must include more than just an assessment of natural processes. In order to accomplish this successfully, a number of steps must be undertaken, as described more closely by HOLLENSTEIN (1997) and HEINIMANN et al. (1998). In a first step, the natural hazard situation must be evaluated. This should be supported by the application of scientific methods, allowing the results to be obtained in an objective and reproducible manner.

Concurrently, in a second step, the damage potential throughout the study area must be evaluated. Depending on the scale, the available data and the goal of the study, the information can be more of a general nature. In regional studies there is a high grade of generalization. Functional object classes are often formed (BORTER 1999). Finally, the spatial intersection of the two preceding layers leads to determination of the zones of conflict (HEINIMANN et al. 1998) (Fig. 2).

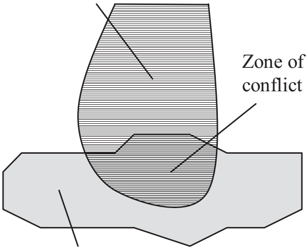

Fig. 2: Concept of a risk analysis according to Heinimann (1998).
Abb. 2: Das Konzept der Risikoanalyse nach Heinimann (1998).

3. IDENTIFICATION AND SPATIAL DELIMITATION OF NATURAL HAZARD PROCESSES

In order to understand the present conditions, and to roughly estimate which processes could potentially affect certain areas in the future, it is necessary to investigate the past. One of the easiest and most effective ways is to evaluate written sources. These can be found in local archives, chronicles, annals and private diaries. It must be taken into consideration that, in spite of the existence of rather long hazard chronicles in Iceland, many documentations, usually only include events directly affecting human lives and assets, such as buildings or farmland. These reports often lack the exact process location, type and extent.

Mapping in connection with the conduction of a risk analysis is always indispensable. Studies require mapping in two steps: First, in form of pre-field mapping, based on the interpretation of aerial photography, and second, in form of process-oriented geomorphological field mapping in the study area. The importance of mapping is great as it serves the purpose of identifying essential features that can often be solely obtained by local investigations. This includes helping to determine the location of avalanche starting zones and rock fall source areas, as well as mapping various deposits. Thus, the mapping of the process starting zones and the corresponding deposition areas are vital for the application and verification of the models and their results. Furthermore, other geomorphological features of importance for determining the hazard potential, such as gullies of transit, various erosion features, and material types are to be mapped, in order to recognize which processes can be expected in which areas. In this study the ‘building block’ method introduced by KIENHOLZ & KRUMMENACHER (1995) was utilized.

Interviews are an essential part of hazard and risk assessments. Especially studies in areas with little or insufficient historic records profit greatly from local experience and knowledge.

Interviews are best made on two levels: On an official level and on a level of local residents. In this study, interviews and discussions took place with members of the community administration, with residents, and with the snow observer, who is responsible for snow depth measurements and avalanche records. There is a snow observer in every endangered town, who has close contact to the central IMO and who generally represents the key person in Icelandic villages with the best general knowledge concerning the natural hazard potential in the areas of investigation.

Computer simulation models can be used as an objective and quantitative approach to the assessment of natural hazard processes. This study introduces the use of two GIS-based computer simulation models to calculate the areas potentially endangered by snow avalanches and rock fall processes. These models were developed for assessments on regional scales and must be clearly distinguished from local scale hazard modeling. While local scale models generally require many input parameters, often having to be obtained by excessive field work, regional scale models usually aim at easily computing maximum runout lengths representing worst-case-scenarios.

The snow avalanche model applied in this study was developed by MEISSL (University of Innsbruck) in 2002 and demonstrates a two step approach using ArcMacroLanguage (AML), implemented in a GIS software (ZISCHG et al. 2002). With the goal of determining the worst-case-scenario, the highest possible starting zones are detected in the field. In the study area, these coincide nearly exclusively with all mountain ridges located above hillslopes with an appropriate gradient of at least 28°, as the model does not consider specific trigger situations, such as snowpack properties or total amount of snow accumulation. Avalanches from these areas possess the highest potential energy. The performance of this avalanche simulation model is carried out in two steps. The first step consists of the trajectory model 'D16', aimed at calculating the predicted path beginning at the various avalanche starting zones. This multiple-flow-direction-process also enables the avalanche movement to undergo a lateral expansion, simulating the growth of avalanche width (ZISCHG et al. 2002). The possible avalanche paths continue in length until they reach the edge of the DEM (Fig. 3, left).

In the following step, the maximum runout distances of the computed avalanche paths are defined based on the avalanche runout model introduced by BAKKEHØI et al. (1983). This model, forming the theoretical foundation, is founded upon geometrical properties of 206 past avalanche occurrences in Norway, employing topographical parameters for the calculation of avalanche processes. The regression analysis leads to the following equation: $\alpha = 0.96*\beta-1.4°$, with SD = 2.3 and R = 0.92 (BAKKEHØI et al. 1983). While α stands for the angle of the line connecting the highest pixel of the starting zone and the furthest known point of the outmost avalanche deposit, β represents the angle between the highest point of the starting zone and the position where the slope inclination equals 10°. This angle is used, because at a gradient below 10° the avalanche begins to impede, resulting in the loss of velocity and energy (BAKKEHØI et al. 1983). Ultimately, this second step defines the surface of a cone commencing at the highest point of the avalanche starting area. The furthest avalanche runout is calculated at the intersection of the avalanche path, determined by the trajectory model as described in step one, and the cone derived in step two (Fig. 3). The final result corresponds to the entire potential avalanche process area.

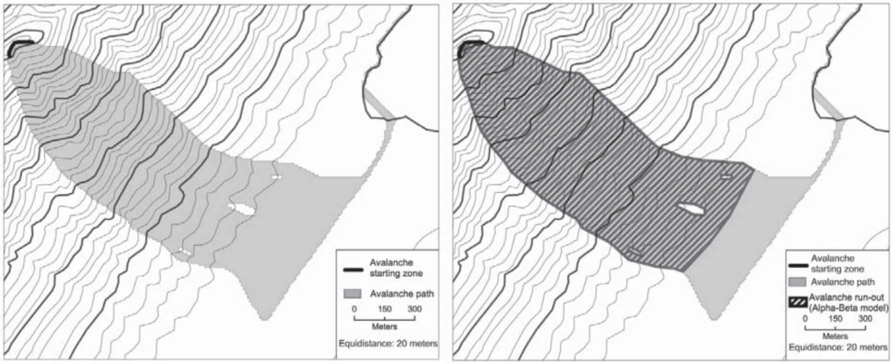

Fig. 3: Regional-scale snow avalanche model (Meissl 2002). Left: Avalanche path as projected by the trajectory model ‘D16’. Right: Determination of maximum runout length according to the principles of the Alpha-Beta model (BakkehØi et al. 1983).
Abb. 3: Lawinenmodel im regionalen Maßstab (Meissl 2002). Links: Lawinenzug ermittelt aus dem Trajektorienmodel ‚D16’. Rechts: Bestimmung der maximalen Auslaufdistanz nach den Prinzipien des Alpha-Beta Models (BakkehØi et al. 1983).

The rock fall model ‘Sturzgeschwindigkeit’ utilized in this study is based on the law of energy conservation, and is likewise implemented in a GIS. It runs in two steps, first simulating a free fall along the rock faces and then, after loosing 75% of its energy on striking the ground surface (BROILLI 1974), the projectile is modeled by a gliding motion on an inclined plain. More detailed information on this model can be acquired in MEISSL (1998).

4. EVALUATION OF DAMAGE POTENTIAL

Apart from examining the natural processes, it is necessary to deal with areas of human assets. Therefore, this investigation focuses on the settled areas within the community area. These are chiefly found along the fjord and in the main Ólafsfjörður valley (Fig. 1). Thereby, it must be differentiated between different types of assets. Three main categories can be defined for this study area, which are representative for most Icelandic regions. First: an urban area - usually a small city or fishing village, second: a network of scattered individual buildings - often farms or summer cottages, and third: transportation and communication lines connecting the settlements. All three of these groups are considered in this risk analysis with respect to human presence and economic significance. The individual objects are mapped by their functions and can be grouped in classes.

5. ESTIMATION OF POTENTIAL IMPACT

One of the main goals of this risk analysis is to determine which human assets are subject to a potential hazard process in a worst-case-scenario. The objects of human interest are intersected with the maximum possible process runout. The computer simulation models applied, in combination with geomorphological field mapping and the analysis of past events, permit a principle delineation of hazard processes on a regional scale. Thus, the results obtained in this study, reveal that the community of Ólafsfjörður is subject to a variety of hazards. The model results show that the newer city expansion located on the lower slopes of the Tindaöxl mountain, includes houses that are subject to potential avalanche runout (Fig. 4). These results are verified by reports of a snow avalanche in the year 1952, which came to a halt directly above the highest houses (JÓHANNESSON & SÆMUNDSSON 1997). In addition, various boulders in the meadows alongside the houses were very likely transported and deposited by avalanches before recent building construction began. There, a large number of residential homes, totaling 82 houses, lie within maximum avalanche runout (Tab. 1). Hence, the lower Tindaöxl slopes deserve to be one of the most important priorities in future investigations. Also, the local hospital is found within possible avalanche runout. Fig. 4 shows further places at risk throughout the study area. These include considerable road segments and two summer cottage areas as defined in the Eyjafjörður Development Plan (2001). Altogether around 25 % of the houses in Ólafsfjörður lie within potential avalanche runout and some 40 % of houses and farms are found within the limits of possible avalanche activity in areas outside of Ólafsfjörður.

Rock fall occurs from numerous basalt bands. The spatial extent of this process is much smaller than that of snow avalanches (Fig. 4). Falling rocks are expected to come to a complete stop on higher parts of the hillslopes, hence neither affecting buildings nor, to any significance, farmland. Only approximately 1,200 meters of road 82 to Dalvík (directly to the northeast of Ólafsfjörður), are subject to rock fall hazard.

Debris flows processes can occur in many places of the study area. Two types can be determined: high viscous debris flows and shallow mudflows. Scars of past mudflow events can be identified throughout the entire area. These processes pose a latent danger to many objects located at the foot of the mountains, especially the houses in Ólafsfjörður at the foot of the Tindaöxl. Higher viscous debris flows are generally bound to pre-existing gullies on mountain slopes. Several road segments south of the lake cross such tracks, as well as approximately 900 meters of the Nr. 82 road northeast of Ólafsfjörður. This segment is exposed to three process types and is considered the most dangerous road section in the study area.

Tab.1: Damage potential and potential hazard process areas in the community of Ólafsfjörður
Tab. 1: Schadenpotential und potentielle Gefahrenprozessbereiche im Gemeindegebiet Ólafsfjörður

Damage potential	Avalanche runout	Rock fall range	Talus and fluvial cones
Within the city of Ólafsfjörður	Buildings	-	-
Residential homes	82	-	-
Recreational buildings	5	-	-
Businesses	2	-	-
Agricultural buildings	2	-	-
Hospital	1	-	-
Other buildings	1	-	
Within the surrounding area	Buildings/road lengths	-	-
Farms	6	-	-
Summer leisure houses	13	-	2
Other buildings	4	-	1
Primary roads	6100 meters	1175 meters	1200 meters
Secondary roads	7700 meters	1200 meters	2600 meters

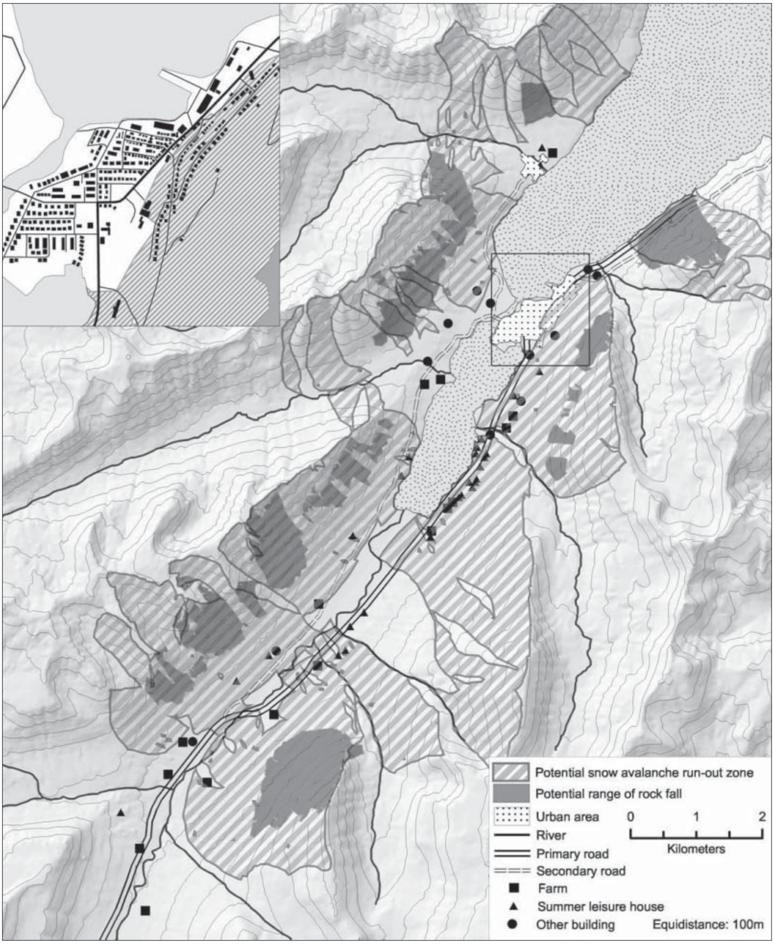

Fig. 4: Zones of conflict.
Abb. 4: Konfliktzonen.

6. CONCLUSION

The results obtained by various field methods and computer simulation models reveal a considerable natural hazard potential in the Ólafsfjörður region. By means of field mapping, investigating historical information and applying computer simulation models, a risk analysis has been conducted with the goal of determining zones of conflict within the study area. These are situated where places of human interests intersect with areas where natural processes can potentially take place in a worse-case-scenario. In the course of this study, emphasis has been placed, first, on natural hazard events in the mountain regions of Iceland, second, on the Ólafsfjörður region, and third, on the performance of a regional scale risk analysis in this typical Icelandic region. This concept was first developed in the Alps and has been now adapted and applied to the community of Ólafsfjörður and its surrounding region.

This study appeals for the instigation of an appropriate regional land use planning concept in the Ólafsfjörður region, in which the results obtained are taken into consideration. The zones of conflict determined in this study represent the places which require further, more detailed investigations on a local scale. In these areas, local scale models are suggested to be applied and precise statements made in regard to recurrence intervals and process intensities. By using this concept, the areas that do not require any further examinations can be quickly excluded, thus saving a considerable amount of time and resources. The goal is to significantly reduce the more time- and cost-intensive local scale analysis, which is to follow. Furthermore, as this study indicates that many houses and transportation routes are exposed to natural hazard processes, the planning and execution of appropriate mitigating measures will be necessary after confirming the results on a local scale. Moreover, these results should be taken into consideration for the planning of concentrated summer cottage areas, as the number of summer cottages is rising in rural areas. Especially for regions in Iceland, still without sufficient hazard assessments, the concept introduced in this study proves to be a quick and effective method.

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