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Natural hazards in Nordic Countries

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Compared to many areas of the world, the human losses caused by natural hazards are smaller in Nordic countries. This is mainly due to the low population density in the exposed areas. However, the economic losses are significant and the geohazards picture varies among the countries. The predominant natural hazards in Nordic countries are floods, landslides, and, with the exception of Denmark, snow avalanche. Volcanoes and earthquakes are major geohazards in Iceland, and parts of Norway are susceptible to seismic activity. Slide-triggered tsunamis also represent a threat to parts of the coastal areas of Nordic countries and Greenland.

Introduction

The paper gives a broad overview of the natural hazards situation in the different Nordic countries. The main focus of the paper is on "geohazards", i.e. natural hazards that are driven by geological features and processes. Geohazards pose severe threats to humans, property and the natural and built environment. Earthquakes, floods, landslides, volcanoes, avalanches and tsunamis are typical examples of such events. Landslides, caused by heavy rainfall, flood, earthquake, erosion, and human activities, are the most common geohazards on land. Near-shore and offshore, various geological processes, earthquakes and human activities, for instance in connection with petroleum exploration and production, can trigger slides and large mass flows.

During 2005, geohazards accounted for about 100,000 deaths worldwide, of which 84% were due to October's South Asia earthquake. In that year, natural disasters affected 161 million people and cost around US\$ 160 billion—over double the decade's annual average. Hurricane Katrina accounted for three quarters of this cost. From 1996 to 2005, disasters were responsible for the deaths of over 934,000 people—nearly double the figure for the previous decade, affecting 2.5 billion people across the globe (World Disaster Report 2006, <http://www.redcross.ca>). Over the decade, 51 people died per natural disaster event in countries of high human development (as defined by UNDP), compared to 573 deaths per event in countries with low human development (Centre for Research on the Epidemiology of Disasters, Belgium). When the trend of fatalities due to natural hazards is studied over the last 100 years, it appears that the increase in the number of deaths is solely due to the increase in the exposed population in this time scale, not an increase in the frequency and/or severity of natural hazards.

Compared to other areas of the world, the human losses caused by natural hazards are small in Nordic countries. This is mainly due to the low population density in the exposed areas. However, the economic losses are significant and the geohazards conditions vary among the countries.

Norway

The main natural hazards in Norway are landslides, snow avalanche, floods and, to a lesser extent, earthquakes (Solheim et al., 2005a). Statistically, 10 large slides can be expected to occur in Norway in the next 50–100 years, each with possibly 20–100 associated deaths. The number of deaths caused by all types of slides in Norway over the past 150 years exceeds 2,000 individuals. Most of these casualties are due to snow avalanche (Figure 1).

Rockfalls and rockslides are among the most serious geohazards in Norway, mainly because of their tsunamigenic potential (Blikra et al., 2002). The three natural disasters causing the largest number of deaths in Norway in the 20th century involved large rock slides in bodies of water generating a tsunami (Loen in 1905 and 1936; Taffjord in 1934, Figure 2).

About 5,000 km² of Norway is covered by soft marine clay deposits; nearly 20% of this area consists of highly sensitive or quick clay. Landslides in quick clay represent a common and serious geohazard in Norway and Sweden. They frequently initiate without warning and turn into a flowing liquid in minutes. Statistically, large quick clay slides involving several million m³ occur in Norway at intervals of about 4 years (Aas, 1981). The largest quick clay slide in Norway in the 20th century occurred at Rissa near Trondheimsfjord in 1978 (Figure 3). It covered an area of 330,000 m² and 5–6 million m³ of clay poured out of the slide area. The largest historical quick clay occurred in Norway in 1893 in Verdal, north of Trondheim. It involved 55 million m³ of clay and caused 116 fatalities, making it the most destructive natural catastrophe in Norway.

A typical quick clay slide is a combination of a minor initial slide and a progressive failure developing very rapidly in all directions from the first slide. For example, the Rissa quick clay slide started with the failure of a small fill at the lakeside. The initial slide involved only 200 m³ of sediments. It grew to about 6 million m³ in a few hours through a retrogressive sliding process.

The seismicity of Norway and adjacent areas is moderate and, even though it is the highest of north-western Europe, it is still lower than in many other 'stable' continental (intraplate) regions (Bungum et al., 2005). Seismicity rates over the 20th century suggest that the region experiences, on average, one magnitude 5 earthquake every 10 years and one M 7 earthquake every 1,100 years. An overview of the data behind these numbers is given in Figure 4, including a frequency-magnitude distribution that is reasonably stable except for the largest events where the time period covered naturally is too short. Earthquakes during this period included two earthquakes with magnitude greater than 5 offshore western Norway in 1988 and 1989, one M 5.4–5.6 earthquake in the Oslofjord region in 1904, in addition to a few offshore earthquakes in the same magnitude range. The largest historical earthquake onshore in Norway, with magnitude 5.8, occurred in 1819 in the Rana region (Muir Wood, 1989).

The average annual cost of flood damage in Norway is about 200,000,000 NOK. After a major flood in south eastern Norway in 1995, the governmental commission gave several recommendations

Figure 1 Left: Snow avalanche in Norway. Right: The Riise snow avalanche in 1968.

Figure 2 Municipality of Fjora in Tafford, Norway, before (left) and after (right) the tsunami triggered by a massive rockslide into Tafford in April 1934.

Figure 3 Quick clay slides in Norway. Left: The Rissa quick clay slide of 29 April 1978. Right: The Trøgstad quick clay slide of 1967 (1 million m³, 4 fatalities).

in order to reduce flood damage in the future. The cost of the damages caused by the 1995 flood amounted to about 1.8 billion NOK (230,000,000 €). One of the recommendations of the commission on flood protection measures was to produce flood inundation maps for the areas with the largest damage potential. This is now an ongoing activity of the Norwegian Water Resources and Energy Directorate (www.nve.no).

The exploitation of offshore petroleum resources, development of oil and gas pipeline corridors, fishing habitat protection, and protection of coastal communities, have contributed to a growing interest in offshore geohazards, in particular seafloor mass movements and their consequences, in Norway. In particular, the ongoing development of the Ormen Lange field, which is the second largest gas

field on the Norwegian Continental Shelf, has contributed greatly to the understanding of the offshore geohazards in Norway. The field is located in the Norwegian Sea in water depths of about 800 to 1,100 m, approximately 120 km from the coastline, within the scar of the pre-historic Storegga slide (Figure 5). The Storegga slide, which took place 8,200 years ago, is one of the world's largest known submarine slides with an estimated slide volume in excess of 3,000 km³ (e.g., Solheim et al., 2005b). Evidence of a major tsunami generated by the Storegga slide has been found along the coasts of Norway, Scotland and the Faeroe Islands. Considering the enormity of the Storegga slide and the potentially catastrophic consequences of a similar event today, it was essential to clarify and quantify the risks associated with submarine slides in the area to obtain approval for field devel-

Figure 4 Left: Evidence of a large prehistoric earthquake on the Stuaragurra (Masi) fault in North Norway, which is part of the Mierujavr'i-Sværholt fault zone. Right: Earthquake distribution in Norway and surrounding regions since 1900 (events > magnitude 3). Inset shows an annual cumulative frequency-magnitude (Gutenberg-Richter) distribution for the area within the polygon (Bungum et al., 2005).

Figure 5 Left: Location and extension of the Storegga slide. Right: The central and deepest part of Storegga slide scar (the Ormen Lange gas field in blue).

opment from the authorities. A major effort was therefore undertaken to evaluate the stability situation of the slopes in the Ormen Lange area today, and quantify the potential risks associated with the field development in the future. The numerous studies carried out in the Ormen Lange offshore geohazards study were summarised in a special volume of *Marine and Petroleum Geology* journal in 2005.

Finland

Finland is located in the path of westerly cyclones, and a large number of stormy days occur especially in winter. The geographical location to the east of the Scandinavian mountain range protects northern and eastern Finland from many major storm effects, exposing mostly southern Finland to related hazards. The rather small size of the Baltic Sea and the structure of large parts of Finnish coastal morphology protect the country from larger storm surges, exposing the coastal areas to flood events by rising water tables during storms (www.gtk.fi/slr). The number of stormy days, as weather extreme events, is likely to increase with climate change. When a winter storm front coincides with a risen sea-level, coastal floods can be a significant threat, as occurred in January 2005. An online description of the effects of this winter storm can be found under www.astra-project.org.

The European-wide natural hazard maps developed by the ESPON 1.3.1 Hazards project (www.gtk.fi/projects/espon) clearly convey the impression of Finland being a country with few natural hazards. The dominant geohazards in Finland are avalanches, landslides, storm surges and winter storms (Schmidt-Thomé, and Kallio 2006). Landslides occur especially on river shores in southern and western parts of Finland among thick clay areas and in the hilly areas in northern Finland. Zooming into the hazard maps on a national scale reveals that river floods are also a prominent natural hazard (Jarva and Virkki, 2006). Finland is characterized by different landscapes, roughly divided into the Finnish Lakeland, west-coast Bothnian and northern Finland riverine areas and southern coastal areas. The water level in large lakes in Finland today is largely controlled leading to a low flood hazard in general terms. Nevertheless in the Bothnian region, spring floods are frequent annual phenomena. In northern Finnish rivers, climate change effects on temperature, ice cover thickness and duration, and changing precipitation patterns might have significant effects on runoff patterns and thus increase the flood risk in the future (Schmidt-Thomé et al., 2006). A national estimate on Finnish major flood hazards showed that the damages caused by an extreme flood with return period of 250 years could cause damages of up to some 550 million Euros (Ollila et al., 2000). Regarding earthquakes, Finland is located on a tectonically very stable craton, so that seismic hazards play only a minor role.

Figure 6 Finnish municipalities with major flood hazard on a regional scale (blue) and municipalities receiving national flood damage compensation (hatched) in period 2000–2004 (After Timonen et al., 2004; source: Schmidt-Thomé et al., 2006).

Denmark

Denmark is a lowland (the highest point about 170 m a.s.l.), with the peninsula Jutland and a number of islands between the Baltic Sea and the North Sea. The country is formed by Quaternary deposits, mainly deposited during the glacial periods 300,000 to 15,000 years ago. The Quaternary deposits have an average thickness of about 30 m, but can reach thicknesses of more than 200 m, which overlie Upper Cretaceous to Neogene sedimentary rocks, dominated by Danian Limestone to the east and Miocene deltaic sediments to the west.

Denmark is not seriously affected by geohazards. There is no volcanic activity and earthquake activity is of minor importance. The last time serious damage due to an earthquake was recorded in 1842, but the event did not cause any casualties. There is no documented damage to the coastal areas of Denmark by tsunami either.

The main geohazard problem in Denmark is landslides, which occur frequently along the cliffed coasts (Pedersen, Foged, and Frederiksen, 1989). The landslides in Denmark can be differentiated into rock falls and mud-dominated landslides (rotational slides). The rock falls are related to the chalk cliffs mainly located at Møns Klint and Stevns Klint at the easternmost coast of Denmark (Figure 7). Møns Klint is one of the key localities of chalk cliff collapse known from northern Europe, which occur at steep coastal cliffs where Upper Cretaceous chalk is exposed (Hutchinson, 2002). In general, cliff collapse takes place in the late winter to early spring, when the ground water saturation is highest and the action of freeze and thaw triggers

Figure 7 Location of major landslides in Denmark (1) Møns Klint, Cretaceous chalk, cliff 100 m high; (3) Western Limfjorden Region mud-landslides; (6–10) mud-landslides.

Figure 8 Upper: The chalk cliffs of Møns Klint. Lower: The most recent landslide at Møns Klint, which collapsed in January 2007 (100,000 m³ chalk created a peninsula 300 m out into the sea) (© SASP).

the rock falls. This type of rock fall characterised the most recent chalk cliff collapse at Møns Klint in the spring 2007 (Pedersen, 2007), where two large falls took place (the larger one is shown in Figure 8).

Mud-landslides are common along the coastal cliffs in Denmark (Figure 7). They develop by progressive back-stepping of crescent-formed décollement surfaces. The formation of the landslides is controlled by three factors: 1) Steep sloping surface; 2) High pore-water flow (generally depending on the lithology); and 3) Erosion of the toe of the slide. The mud-landslides cause constructional problems, but so far no human casualties. These landslides create a problem in parts of the attractive coastal environments. However, the cost of private property is not regarded high enough compared to the cost of coastal protection, thus no active protection or mitigation is provided by the public services.

Greenland

Greenland is the largest island in the world with an area of 2,166,000 km², of which 410,000 km² are bedrock, and the remaining area is covered by the inland ice reaching a thickness of more than 3 km. Very few geohazard problems have affected the Greenland population, which consists of about 60,000 inhabitants. There is no recent volcanic activity in Greenland; and earthquakes, caused mainly by the displacements in the inland ice, are only of minor importance. However, landslides and rock falls can cause serious problems.

The landslides in Greenland are influenced by permafrost, glacial ice, high topographic relief, and repeated freezing and thawing (Pedersen, 1987; Pedersen et al., 1989). In most parts of Greenland, however, where gneiss and granite dominate, slides are rare. In contrast, the Nuussuaq Basin in central part of West Greenland comprises weakly consolidated sedimentary rocks overlain by a thick

Figure 9
Above: The Pattutt slide in Western Greenland. Right: Coastal areas of western Greenland susceptible to rock slides with tsunamigenic potential.

pile of dense volcanic rocks. This stratigraphical succession is favourable to the generation of slides. Consequently, large parts of Disko, Nuussuaq and Svartenhuk Halvø are strongly affected by landslides (rock falls, disrupted slides and avalanches), especially along the coasts (Figure 9). It is not the landslides themselves that have been disastrous, but the tsunamis related to landslide out into the deeper parts of the sea. These dangerous landslide and tsunami events appear with a frequency of one per 50 years.

The latest event occurred in November 2000, which was investigated in detail by the Geological Survey of Denmark and Greenland (Pedersen, 2002). Late in the afternoon November 21, 2000 the coast at the settlement Saqqaq was flooded by a series of giant waves triggered by a 90 million m³ landslide from a cliff (1,400 m a.s.l.) (Figure 9). Ten boats were destroyed, but luckily no humans were killed. About 30 millions m³ of the landslide flowed seawards, triggering the tsunami. The velocity of the tsunami was calculated to be 240 km/h, corresponding to the depth of 450 m in Vaigat and to the time interval between the landslide-induced tsunami initiation and the registration of the waves in Saqqaq.

Iceland

Among the Nordic countries, Iceland is the one that is most exposed to geohazards. Volcanic and seismic activity is pronounced in Iceland due to its location on the Mid-Atlantic Ridge. Frequent earthquakes and eruptions occur along the boundary between the North-American and Eurasian plates that runs through Iceland as a series of seismic and volcanic zones (e.g., Einarsson 1991; Sigmundsson, 2006). A comprehensive record extending over 1,100 years as well as present-day good instrumentation and extensive research have revealed the nature of the hazards. In addition to volcanic and seismic hazards, Iceland has major avalanche hazards due to its northerly latitude and rapidly changing climatic conditions.

The volcanic zones of Iceland are comprised of about 35 main centres of volcanic activity. In historical times there have been about 20 eruptions per century, or one eruption about every 5 years on average (e.g., Thordarson and Larsen, 2007). Three volcanoes, Hekla (Figure 10), Katla, and Grímsvötn, are by far the most active in Iceland. The first post-settlement eruption of Mt. Hekla in 1104 A.D. was a major explosive eruption that produced about 2.5 km³ of rhyolitic tephra, blanketing large parts of Iceland and causing complete destruction of the nearby inhabited areas. Through historical time, one or two major eruptions occurred each century at Hekla until 1947 (Thorarinson, 1967). Thereafter, the eruptive pattern changed to more frequent and smaller eruptions. The initial phase of many Hekla eruptions is explosive and has spread tephra over large parts of Iceland. At Hekla, soluble fluorine adheres to erupted tephra particles, leading to lethal fluorosis in grazing animals even in areas of minor tephra fallout (Óskarsson, 1980). Other volcanoes with large explosive eruptions include the Askja volcano in 1875, and in 1362, a large explosive eruption of Mt. Örfajökull devastated large areas in SE-Iceland.

A number of Iceland's volcanoes are subglacial, including the Katla and Grímsvötn volcanoes. Eruptions at these volcanoes can cause rapid melting of huge amounts of ice (e.g., Gudmundsson et al., 1997). Major glacial outburst floods associated with such eruptions, volcanic jökulhlaups, are more frequent in Iceland than elsewhere in the world and are a particular hazard. Katla eruptions, once or twice each century throughout Iceland's history, have produced large quantities of airborne tephra, as well as major huge glacial outburst floods with estimated peak flow rate

Figure 10 Left: Eruption of Krafla Volcano in 1980. Right: Eruption of Hekla Volcano in 2000.

Figure 11 Satellite photo of the Vatnajökull ice cap.

exceeding 100,000 m³/s (Larsen, 2000). The Grímsvötn volcano under the Vatnajökull ice cap (Figure 11) has the highest eruption frequency of all volcanoes in Iceland and produces frequent jökulhlaups. However, only a fraction of them are associated with eruptions as many of them are due to storage of water and melting of ice by geothermal heat within the subglacial Grímsvötn caldera. Jökulhlaups originating from the Katla and Grímsvötn volcanoes have produced large outwash plains downstream from the affected glaciers. These outwash plains, termed "sandur" in Icelandic, have been greatly augmented in historical time in Iceland. They are zones of particular hazards in the case of subglacial eruptions.

In addition to hazards from tephra and jökulhlaups, large quantities of lava have been erupted in effusive eruptions during historical time in Iceland. Whereas most of the lava forming eruptions are small in volume (on the order of 0.1 km³), two exceptionally large volume eruptions have occurred, including the largest historical lava flow on Earth (witnessed by man). The Eldgjá eruption in 934 A.D. has an estimated volume of 19.6 km³ (Thordarson et al., 2001) and the 1783–1784 Laki eruption produced 15 km³ of lava (Thordarson and Self, 1993). Both eruptions mark major rifting episodes consisting of a series of eruptions associated with dike intrusions accommodating plate spreading, and their environmental effects were tremendous. Widespread air pollution associated with the Laki eruption led to the death of livestock by fluoride poisoning and subsequent famine in Iceland. The population of Iceland decreased from about 50,000 before the eruption to about 40,000 in the years

after, and the eruption also had an impact on living conditions in Europe. Smaller lava flows provide a threat as well. A small volume eruption on the Heimaey Island in 1973 had a major influence, as it occurred within a village, causing temporary evacuation and considerable destruction of the village.

Seismicity in Iceland is concentrated in two transform zones, the South Iceland Seismic Zone and the Tjörnes Fracture Zone, each associated with a lateral shift in plate spreading (Figure 12). They experience persistent micro-earthquake activity and earthquakes as large as magnitude 7–7.5 (Ms) occurring in a series, typically about once each century. Dates of the largest earthquakes in South Iceland are known back to the 12th century, pointing to sequences of major damaging earthquakes in the South Iceland Seismic Zone at average intervals of 80–100 years (e.g., Einarsson, 1991). A country-wide seismic network in Iceland, composed of three-component digital seismic stations run by the Icelandic Meteorological Office (<http://www.vedur.is>), records well the present day seismicity in Iceland (e.g., Jakobsdottir et al., 2002). Within the volcanic zones, background seismicity is focused at the central volcanoes where elevated earthquake activity is there often associated with magmatic movements that cause temporarily high local stresses. Such magmatic movements are most frequent at the central volcanoes, but major seismic activity also occurs in the fissure swarms during rifting events. Extensive crustal deformation studies have revealed how magma moves in the crust (e.g., Sturkell et al., 2006; Sigmundsson, 2006).

Figure 12 Tectonic map of Iceland.

The last decade includes some significant tectonic and magmatic events in Iceland, including a major earthquake sequence in South Iceland in 2000, with Ms 6.6 events occurring on June 17 and June 21. Maximum fault slip was 2.5–3 meters (e.g. Pedersen et al., 2003) and triggered seismic activity followed the initial seismic event occurred farther to the west along the plate boundary (e.g., Arnadóttir et al., 2003). Significant earthquake activity immediately precedes most eruptions in Iceland (in association with a formation of a feeder dyke), changing at the onset of eruptions to volcanic tremor that continues throughout the eruption as long as magma flows to the surface (e.g., Vogfjörð et al., 2005).

Snow avalanches are a major geohazard in Iceland and have claimed over 600 lives throughout Iceland's history (Björnsson, 1980). In the period 1901–2000, landslides claimed 27 lives and snow avalanches 166 lives (Jóhannesson and Arnalds, 2001). The main avalanche areas are in the steep coastal areas outside the seismic and volcanic zones. Presently, the avalanche risk is most pronounced in threatened coastal villages and a major avalanche protection plan is being carried out (Haraldsdóttir et al., 2006). In recent decades, the largest natural disasters in Iceland were two snow avalanches in Northwest Iceland in 1995 that claimed together 34 lives.

Landslides, in particular debris flows on slopes in fjord environments, occur regularly and cause considerable damage in Iceland. The slopes are glacially over-steepened, and are typically covered with shallow regoliths comprised of till and colluvium. The main source of debris is the rapidly weathered basaltic cliffs that form the upper parts of the slopes and the inherited glacial material still available on the intermediate benches. Debris flow activity in Iceland has been recorded all year round, but the activity level is higher in late spring, late summer and autumn.

There are some regional differences in the meteorological factors for debris flow initiation (Decaulne and Sæmundsson, 2007). Snowmelt is the most common triggering factor in North Iceland (35%), while it represents the third most common one in Northwest Iceland (19%), and is hardly represented in East Iceland (4%). Snowmelt associated with rainfall controls around 24% of the debris flow releases in both the Northwest and North fjords. It also represents the largest proportion of triggered nival debris flows in East Iceland (14%). Long-lasting rainfall is the most common pluvial triggering factor in all fjord areas. It controls almost 50% of the debris flow events in East Iceland; it is the primary cause of debris flows in Northwest Iceland, and the third most important triggering factor in North Iceland. Intense rainfall is the second most important triggering factor in East Iceland, causing more than 30% of the pluvial debris-flows.

Sweden

The major geohazards in Sweden are landslides, floods and snow avalanches. Most of the Swedish Quaternary deposits and minor terrain configurations are a result of the deglaciation of the latest continental ice sheet. Due to the pressure of the weight of the inland ice, lowlands were submerged during the deglaciation. Marine conditions prevailed in southwestern Sweden while fresh water or water with low salinity occurred in the Baltic basin up to Bothnian bay. As soon as the pressure of the inland ice started to lighten, the crust began to slowly rebound. The highest traces of the shoreline are at different altitudes throughout Sweden, depending on how far the crust had been depressed, how much the local sea surface had transgressed, and the time at which the area became deglaciated. The highest shoreline is at 286 m a.s.l. on the coast of central northern Sweden. In the south, the highest shoreline coincides almost with the present shoreline. The rate of the present land uplift is almost 9 mm per year along the coastland of northern Sweden.

Figure 13 Munkedal landslide (2006) affecting the Oslo-Gothenburg traffic.

Most common types of mass movements in Sweden are found in areas below the highest shoreline. They are formed in connection with snowmelt and the thawing of frozen ground, as well as intense or prolonged rainfall, i.e. when the water pressure in the ground is high, or when there are sharp fluctuations in the groundwater level. Large landslides have become increasingly common during the past century, most likely as a result of anthropological interference, e.g. by construction activity that undercuts or overloads dangerous slopes. The landslides in Sweden mostly occur in relatively gentle slopes made up of glacial silt and clay, mainly in quick clay. Most of the dangerous slopes are bordered by open water—a river or a lake. About 4% of the land surface consists of clay and silt. Based on known landslide scar frequency (Figure 14, left), about one per cent of the land surface is highly susceptible to spontaneous landslides.

Many of the largest and most costly landslides in Sweden have taken place in the River Göta älv valley and its surroundings between Lake Vänern and Gothenburg. The total volume eroded by landslides and gullies in that valley is calculated to be roughly 500 million m³. The latest large landslide with significant casualties

Figure 14 Sweden: Most susceptible slide areas (left) (www.sgu.se) and flood risk map (right) (www.srv.se).

occurred at Tuve on 30 November 1977. The slide severed seven electric cables and completely destroyed 65 single-family houses, killing nine people. The consequences of a landslide are not always proportional to its size. On 1 October 1918, a small landslide with disastrous consequences occurred at Getå on the slope to Bråviken Bay. A train with about 300 passengers crashed at full speed into the slide. Fire broke out in the wrecked wagons. Some 40 victims were identified, but the exact number of casualties is not known.

Landslides represent a major threat to the communication infrastructure in parts of Sweden. For example, as recently as 20 December 2006, part of Highway E6 near Munkedal in Bohuslän in the west of Sweden collapsed in a landslide (Figure 13). The E6 is the main road between Oslo and Gothenburg. The landslide caused major disruption to traffic as the 15,000 vehicles that passed the collapsed section of road every day had to be rerouted for several weeks. The site of the landslide was the most recently opened section of the E6, which has been undergoing rebuilding work. The cause of the landslide is not known, but there is speculation that the construction activities and unusually heavy rain that had recently hit the area could have triggered a quick-clay slide. The Bohusbanan railway line, which runs parallel with the E6 road, was also affected. The landslide destroyed the railway embankment and cut an electricity line leaving the railway without power.

Almost every year Sweden is affected by floods resulting in damage. Damage can be limited through prevention planning and effective response operations during flood emergencies. For this purpose the SRSA (Swedish Rescue Services Agency) compiles and maintains general flood inundation maps (Figure 14, right). These are created as basic data for prevention work with the help of a watercourse model for those areas close to watercourses that are at risk of flooding. The maps are intended for use during the planning of emergency and rescue services work and as a foundation for land use planning by municipalities. They can also be used as basic data for various risk and vulnerability analyses.

Concluding remarks

The predominant natural hazards in Nordic countries are floods, landslides, storms and cyclones, and, with the exception of Denmark, snow avalanche. Volcanoes and earthquakes are major geohazards in Iceland, and parts of Norway are susceptible to seismic activity. Quick-clay slides pose a major threat in Norway and Sweden. Slide-triggered tsunamis also represent a threat to parts of western Norway and the coastal areas of Greenland and Iceland.

However, compared to many areas of the world, the human losses caused by natural hazards are smaller in Nordic countries. This is mainly due to the low population density in the exposed areas. The economic losses, on the other hand, are significant and the societal risks posed by natural hazards vary significantly from country to country in Norden. The results of recent research projects imply that the temporal and spatial distribution of natural hazards in Nordic countries might increase significantly in the coming decades because of climate change. Adapting to the new situation will require a proactive approach from the politicians, geoscientists and decision makers.

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