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Societal consequenses of landslides – landslide risk mapping in Säveån river valley, Sweden

Conséquences sociétales des glissements de terrain – cartographie des risques de glissements de terrain dans la vallée de la rivière Säveån, Suède

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ABSTRACT: Measures to prevent landslides are an important part of the urban planning process, both with regard to the present-day climate and to long-term climate change. Landslide risk maps provide an illustration of the location of sensitive areas that may require investigation in more detail. These illustrations are achieved by mapping the geotechnical conditions and the societal consequences that could arise in conjunction with a landslide. Landslides could potentially impact a large number of people and key societal functions. Alongside the computation of the probability of a landslide in the land-slide risk mapping, the consequences of a landslide in the river valley also need to be assessed. In this study, the consequences for buildings and transport routes in the area of analysis, as well as contaminated areas (MIFO-classified areas), were evaluated qualitatively based on four aspects: life, environment, economic impact and societal function. The classification was performed in a GIS-environment using nationally available data of buildings, roads and railway networks. Contaminated land areas were digitized and classified in cooperation/collaboration with the County Administrative Board and local authorities. The consequences were divided into five categories and visualised in 10 x 10 m squares. This paper traces the methodological potentials and challenges of valuing and mapping the societal consequences of landslides in the Säveån river valley, in southwestern Sweden.

RÉSUMÉ: Les mesures de prévention des glissements de terrain constituent un élément important du processus de planification urbaine, en ce qui concerne tant le climat actuel que le changement climatique à long terme. Les cartes des risques de glissements de terrain fournissent une illustration de l'emplacement des zones sensibles à étudier plus en détail. On y parvient en cartographiant les conditions géotechniques et les conséquences qui pourraient survenir lors d'un glissement de terrain. Les glissements de terrain pourraient avoir des répercussions sur un grand nombre de personnes et sur des fonctions vitales de la société. Outre le calcul de la probabilité d'un glissement de terrain dans la cartographie des risques de glissement de terrain, les conséquences d'un glissement de terrain dans la vallée fluviale ont également été évaluées. Les conséquences pour les bâtiments et les voies de transport dans la zone, ainsi que pour les zones contaminées (zones classées MIFO), ont été évaluées qualitativement sur la base de quatre aspects : la vie, l'environnement, l'impact économique et la fonction sociétale. La classification a été effectuée dans un environnement SIG, en utilisant les données disponibles à l'échelle nationale sur les bâtiments et les réseaux routiers et ferroviaires. Les zones terrestres contaminées ont été numérisées et classées en coopération/collaboration avec le Conseil du Comté ainsi que les autorités locales. Les conséquences, divisées en cinq catégories, ont été visualisées en carrés de 10 x 10m. Cet article retrace le potentiel méthodologique et les défis liés à l'évalutation et à la cartographie des conséquences sociétales des glissements de terrain dans la vallée de la rivière Säveån, Sud-Ouest de la Suède.

Keywords: Landslide risk analysis; societal consequenses; climate change

1 INTRODUCTION

Society needs to adapt to a changing climate and consider its consequences when planning buildings and infrastructure. Effective climate adaptation requires not only knowledge and decision support tools that are flexible, multidisciplinary, and place-based, but also tools that can be implemented and coordinated at regional level.

Many areas in Sweden are susceptible to landslides, particularly areas along watercourses flowing through layers of loose soil. In these vulnerable areas, the effects of climate change may be very tangible, e.g. when a higher water flow causes increased erosion and a deterioration in soil layer stability.

The aim of SGI's (Swedish Geotechnical Institute) landslide risk mapping is to provide an overall picture of the landslide risks along specific watercourses, not only under current conditions but also from a long-term perspective stretching to 2100.

Expanding on the extensive work done in the Göta river valley Investigation (GÄU) (SGI 2012), SGI has developed methods for mapping landslide risks that can be applied to other watercourses (Odén et al 2017). The method developed in the GÄU was inspired by the landslide risk analysis of Alén et al (2000). Examples of other methods that were considered in subsequent landslide risk analyses took gudiance from the risk and vulnerability analyses produced by the Norwegian Authority for Social Protection and Preparedness (DSB 2014), methods for risk assessment of coastal erosion (Rydell et al. 2012) and methods for multi criteria analysis (Andersson-Sköld et al. 2011).

The paper first describes the overall risk method used in the Säveån river valley analysis (SGI 2017) and then focuses specifically on how the method to analyze consequences of landslide was developed together with stakeholders in the region, including the challenges and potentials of the method. In conclusion this paper points out some of the lessons learned from the Säveån river valley analysis and suggests continued directions for SGI's work with landslide risk analysis.

2 PROBABILITY, CONSEQUENSES AND RISK

Landslide risk in the SGI analyses is defined as a combination of the probability of a landslide and the consequences of a landslide.

The probability of a landslide and associated consequences are then combined in a risk matrix, see Figure 1. The risk is categorised on three levels – high, moderate and low – and with three corresponding colours – red, orange and yellow – on the maps showing the landslide risk. Red risk categories represent the highest risk, orange categories a medium risk and yellow categories a low risk for landslide.

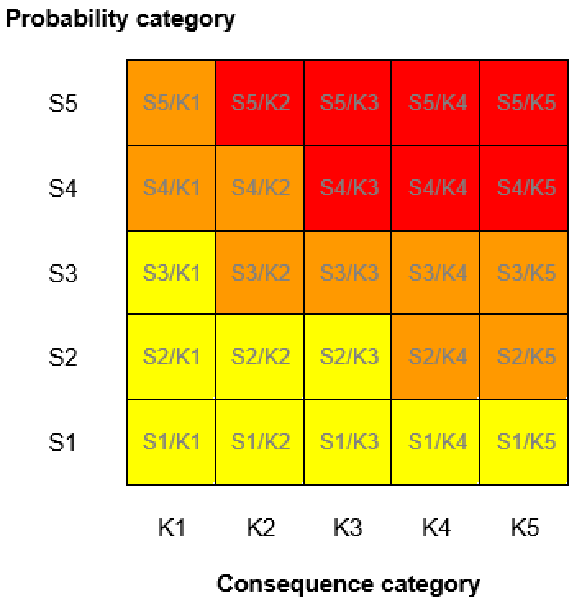

Figure 1 Matrix of landslide risk levels

The survey method used in mapping the Säveån river valley represents a general level of probability and consequences, where a qualitative assessment of the consequences has been carried out, and thus also a qualitative evaluation of the landslide risk.

3 ANALYSING THE CONSEQUENCES OF LANDSLIDES

The aim of SGI‘s consequence analysis has been to provide a transparent, simple, useful and general method for visually identifying the consequences of a landslide.

The method has been developed from several sources, including Rydell et al‘s method to value consequences of coastal erosion (Rydell et al. 2012), which was inspired by McLaughlin and Cooper‘s work with a coastal vulnerability index (McLaughlin och Cooper 2010).

The method builds on the compilation of a map that is divided into 10 * 10 meter grid squares. Each square is given a consequence class based on the data layers that are included in the method and on assessment of four quality criteria; life, environment, economy and societal function.

If several objects are present in the same grid square, the object with the greatest value determines the consequence category of the entire grid square.

The consequences have been divided into five categories, where the division is linked to the classification from earlier landslide risk investigations and represents gradual increasing consesequences, see Table 1.

Table 1 The table shows the colour markings that represents the consequence categories in the map.

Colour	Category	Description of consequences
	5	Catastrophic
	4	Extremely serious
	3	Very serious
	2	Serious
	1	Minor

Experience from the GÄU (SGI 2012) survey shows that it is very resource-intensive to produce monetary values of sufficient quality regarding consequences of landslides. Therefore, when a general method was to be developed for subsequent landslide risk analyses, it was decided to use qualitative values rather than monetary values. The development of a qualitative method began with the landslide mapping of River Norsälven and continued with the analysis of Säveån. The transition between a monetary method to a qualitative method and the simplifications made to make the method more general, but still relevant for local use, was not an easy task. But it laid the foundation for further development of a feasible qualitative method.

In order to develop a general method that can be applied throughout Sweden, it was decided to use available data from Lantmäteriet (The Swedish Mapping, Cadastral and Land Registration Authority) for transport infrastructure and builings. In the Göta river survey, these consequences were identified as two of the most important and common consequences of a landslide. A further development in the Säveån analysis was to include a new consequence - contaminated areas (Löfroth et al. 2012). The County Administrative Board of Västra Götaland provided information about contaminated areas, so callad MIFO-areas.

Thus, the consequence assessment was delimited to three data layers representing three of the most important objects affected by landslides:

- Transport infrastructure
- Buildings
- Contaminated areas

The method is not an exhaustive description of all possible consequences. For instance power infrastructure and surfaces like parks and camping areas could be important consequences to consider. In further development of the methodology for the Ångermanälven river basin some of these consequences are currently being considered in more detail.

For the Säveån river valley analysis, the two data layers from Lantmäteriet each contained several types of objects. The transport infrastructure layer contained 36 types of infrastructre, for example different classes of public roads, highways, single-track railways, etc. The building layer contained 49 types of buildings, for example apartment buildings, health centers, or waterworks.

The identification process of the contaminated area-sites was done in collaboration with the County Administrative Board in Västra Götaland. In all, 119 potentially contaminated areas in Säveån´s investiagtion area were identified, but only the contaminated areas that were believed to have greatest impact on the aquatic environment, in case of a landslide, were included in the consequence assessment. This brought the total number to 23 areas.

To evaluate each data layer in a qualitative, simple and transparent way, four assessment aspects were selected:

- Life
- Environment
- Economic impact
- Societal function

Life

The assessment of the life-aspect concerns the estimation of the number of people in each object who may be affected in a landslide. For example, a multi-use arena may house a huge number of people at the same time with potentially catastrophic consequences for life. While the life aspect is important to assess for buildings, it is less so for transport infrastructure, since the number of people potentially affected in using an infrastructure object are usually fewer than in many types of buildings. For contaminated areas, the life-aspect was not as important as the environmental aspect, as relatively few people might be directly affected by contaminates in the event of a landslide.

Environment

In the assessment of the environmental aspect, direct pollution spread, long-term impact and geographical distribution were included. The environment can be affected to varying extents mostly depending on the size of the affected factory, contaminated area or transport-object, and by the type of chemicals that are spread. The environmental-aspect is less important to assess for the transport infrastructure layer as it is for contaminated areas and buildings, due to the lesser probability that a hazardous goods transport will be affected in a landslide than a permanent chemical factory or contaminated area.

Economic impact

In the assessment of the economic aspect, the value of a building, the ground it stands on, and the value of manufacturing or activity (income, machinery, stock goods etc.) were included. For the transport infrastructure layer the economic aspects were assessed regarding rerouting needs, reconstruction and impact of a landslide on trade and industry. The national significance of a road and railroad, identified through the "national interest classification", raised the economic value of roads and railways. Contaminated areas were not assessed regarding the economic aspect due to the large uncertainties involved in calculating the cost of remediation.

Societal function

The assessment of societal function was based on the objects' importance for the society. Some objects have a life-saving significance, for example hospitals, waterworks and power stations. Transport infrastructures were assessed based on their function to maintain significant communication routes. Assessment of societal function was not assessed as relevant for contaminated areas.

Through discussion and through an iterative approach, a working group allocated a value for each type of object, based on the four aspects. The values of the objects were set in relation to each other, and within each individual data layer.

Because the value of each object had to be a general value, rather than being based on its function at a specific location, it was a challenge for the working group to decide on an appropriate value for each object. For example, comparing a large chemical factory to a small paint shop will yeild different consequences, but it is possible that both are classed as "chemical industry" in Lantmäteriet's data layer and given consequence value 5. This uncertainty is apparent in all three data layers.

In order to give greater legitimacy in the analysis (Oen et al 2016), the valuation method used in the Säveån consequence analysis was augmented by a common stakeholder workshop held with the municipalities and County Administrative Board in the area of analysis and discussions with planners in the municipalities along the river – Lerum, Partille and Gothenburg. Thus, during these activities officials in the municipalities were given the opportunity to suggest changes regarding both the type of object, and their consequence values. This increased the quality of the analysis and solved some of the problems when the general consequence valuation did not match the actual conditions.

GIS

Following the valuation state, a GIS analysis (Geographical Information System) was performed in ArcGIS 10.3.1 including Spatial Analyst Extension. A combination of raster and vector analyzes and tools (ArcGIS Tools) was used. The majority of workflow was implemented in Model Builder. This facilitates reuse and repeated runs with modified input data.

Both transport infrastructures and buildings were buffered by 20 meters. Buffring was made to make the objects more visible and to include the immediate surroundings. Changes in objects or valuations of objects suggested by stakehodlers were made by hand.

Potentials and challenges of mapping and valuing consequences

In general the valutation process progressed smoothly. By using existing and accessible data, objects could be given a fixed value category that was general and comparable for the entire area of analysis. A general principle new to the Säveån river valley analysis was that the consequence values for transport infrastructure and building objects were valued releative to each other. An assumption was made that the consequences of loss of lives if a road was damaged by a landslide would be less serious than if a building housing numerous people at one time, were damaged. Thus road classes were valued slighty lower than buildings. This valuation did not take into consideration the properties of the object in reality, its size or importance and thus results may not reflect these concerns. Thus some objectives were re-valued and re-classified by stakeholders and experts in the municipalities and the county. Primarily roads were re-classified, particularly if they were important diversion routes in the event that a main road or motorway was inaccessible, or if they were a motorway with national importance. Figure 2 shows the various consequence categories in part of the area of analysis. As seen in the figure the main catastrophic consequence is the European motorway 6 (E6), which was valued up one category due to its national importance, as well as a major railway line which is in the highest consequence category. Other types of buildings and infrastructure were valued as having extremely serious or very serious consequences.

But bringing in elements that were more subjective (but more realistic) to the valuation posed some methodological challenges. As each municipality was asked to assess the valuation of the buildings, transport infrastructure and contaminated areas, theses values could be quite specific to an area. For instance one municipality felt that objects of high cultural heritage value (such as a church) should be included in the valuation. However, unless each municpality valued cultural objects in the same way, it was difficult to apply a general and systematic cultural valuation method across the whole area of analysis, spanning the three municipalities.

Several other consequences were excluded from the analysis. With regard to environment, natural values were difficult to value as landslides can have both positive and negative effects for biodiversity. Various types of power and water and sewage networks were also excluded from the analysis, as this information is not always publically available.

As discussed above, the object with the greatest value determined the consequence category, even if there are several other objects within the same grid square. A downside to this is that other objects with lower value are not as visible.

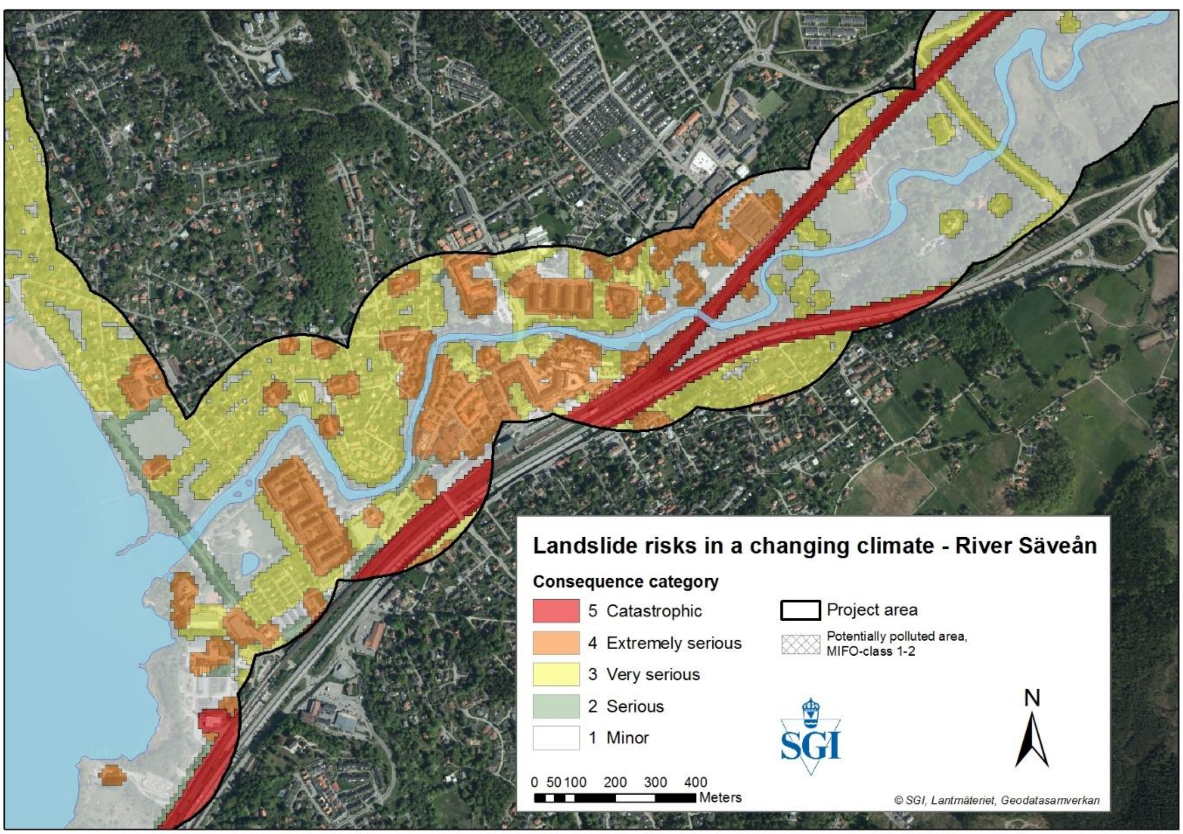

Figure 2 Mapped consequence categories in an example area of the landslide risk analysis along River Säveån.

4 CONCLUSIONS

The improvements to the method development for valuing consequences in the Säveån river valley analysis were tested together with input from local and regional stakeholders in the area. While these changes in methods and involvement of stakeholders have made the process more realistic and useful for stakeholders, further method development is still possible. These improvements include developing a more systematic method for co-creation utilizing local expertise to increase legitimacy (Van Well et. al 2018), and considering various types of multi-criteria analysis together with stakeholders to make the valuation method more transparent. In this way it may be possible to include more environmental and cultural values, as well as more knowledge on the effects of spread of contaminated soil and water during a landslide. SGI has to some extent taken these aspects into account in its current landslide risk analysis of the Ångermanälven river basin. While there is still room for improvement of the method in subsequent analyses, more elaborated methodological developments must be weighed against the task to provide a transparent, cost-effective and general analysis.

SGI's mission in its landslide risk analysis is to provide a robust and relevant knowledge base about the probability and consequences of landslides, in a changing climate. The aim of the landslide risk analysis is to faciliate decisions about safety for existing buildings, infrastructure and societal functions, as well as planning for new exploitation. As the method for the consequence analysis continues to be developed, SGI strives to provide a general analysis which can be augmented by more specific and in-depth analysis performed within each municipality and using local data and knowledge.

5 ACKNOWLEDGEMENTS

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The study is presented in full in the SGI report “Landslide risks in a changing climate – Säveån river valley”, SGI Publication No. 38-1, 38-1E (English version), 38-2 and 38-3, 2017.

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