# Tools for Natural Hazard management in a Changing Climate

## Outils de gestion de désastres naturels dans un climat changeant

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ABSTRACT: The paper will give an overview of some existing tools and models that can be used for risk analyses due to natural hazards (landslides, erosion and consequences of flooding) in a changing climate. Tools from several countries have been investigated by a literature survey and a questionnaire. A more comprehensive tool developed by Swedish Geotechnical Institute (SGI) will be presented more in detail. A compilation of tools has been carried out in the project "Baltic Climate", funded by the EU Baltic Sea Region Programme 2007-2013 and its partners. The investigation shows that there is a general lack of tools for soil movements in the countries in the Baltic Sea Region and that most of the existing ones don´t take climate change into consideration. The paper will present a model that can be used separately or as a complement to more general tools for spatial planning. The tool for soil movements considers the consequences of flooding, landslides and erosion in a changing climate and it can be used on both regional and local levels. The tool is described as a general method with examples from municipal level. The SGI tool has been used in several practical cases both on a regional and local level.

RÉSUMÉ: Cet article donne un aperçu de certains des outils et des modèles existants qui peuvent être utilisés pour l'analyses de risques reliés aux désastres naturels (glissements de terrain, l'érosion et les conséquences des inondations) dans un climat changeant. Des outils provenant de plusieurs pays ont été étudiés par une étude bibliographique et par questionnaire. Un outil plus complet développé par l'Institut Suédois de Géotechniquev (SGI) sera présenté plus en détail. Une compilation d'outils a été réalisée dans le projet «Climat Baltique», financé par le programme de l'UE de la mer Baltique 2007-2013 et de ses partenaires. L'étude montre qu'il y a un manque général d'outils pour les mouvements du sol et que les outils existants ne prennent pas en compte les changements climatiques. Cet article présente un modèle qui peut être utilisé séparément ou comme un complément à des outils plus généraux de l'aménagement du territoire. L'outil des mouvements de sol considère les conséquences d'inondations, de glissements de terrain et de l'érosion dans un climat changeant et il peut être utilisé au niveau régional ou local. L'outil est décrit comme une méthode générale avec des exemples au niveau municipal. L'outil SGI a été utilisé dans plusieurs cas pratiques aussi bien au niveau régional que local.

KEYWORDS: tool, natural hazard, landslide, erosion, climate change

## 1 INTRODUCTION

In order to establish resilient communities, mitigate damages, adapt the built environment and establish a sustainable society, there is a need for a sound decision basis for buildings, infrastructure, industry and the environment. One cornerstone to reach a sustainable development is to take natural hazards into account both for the situation today and for the consequences of climate change. The predictions of global climate change include sea level rise, in many countries increased precipitation and runoff and more intense and damaging storms which will increase the threats of natural hazards.

## 2 NATURAL HAZARD MODELS IN CLIMATE CHANGE

In this paper tools are presented that can be used in a climate change adaptation process, with focus on natural hazards such as landslides erosion and flooding, There are also review of more general tools, e.g. "The Baltic Climate Toolkit" which can be used for planning on the regional, local and detailed level. The main purpose of the toolkit is to highlight the importance of climate change mitigation and adaptation aspects in spatial planning [1].

The "The Baltic Climate Toolkit" is developed within the project Baltic Climate (BC) [1]. Adaptation to the future climate conditions, including flooding etc. should be one of the starting points of the planning process proposed in the BC-toolkit.

The comprehensive decision process model described in this paper focuses on natural hazards such as erosion and landslides (soil movements). It constitutes a part of the Baltic Climate project and can be used individually or as complement to the general toolkit for aspects regarding soil movements. It can be used for adaptation aspects especially for spatial planning or in built-up areas to ensure a safe, healthy and sustainable society. The investigation was done by a questionnaire sent to the partners and associated organisations in BC complemented by a brief literature survey.

In addition to the presentation of the decision process model, a practical application of the model in a municipality is presented. The investigation constituted a part of the BC project. According to the results provided by the respondents several countries have started investigations to identify risks of natural hazards such as coastal erosion, landslides and flooding, but the investigations do not always incorporate the effects of climate change. Furthermore, the investigations are normally restricted to currently developed areas [1, 2]. The investigation in the Baltic Sea Region showed that there is a general lack of tools for soil movements and they don't consider the impacts of climate change. However, in Sweden there is a model, developed by the SGI, which is presented in this paper.

The questionnaire survey of tools/models of soil movements was also expanded to outside the Baltic Sea Region. A questionnaire was completed by respondents in France, Hungary, Italy, Norway, Poland and Slovakia. In all responding countries models for soil movements are in use. The models presented from Hungary, Italy, Poland and Slovakia do, however, not take climate change into consideration.

The literature survey revealed that a large range of conference papers can be of interest when working with soil movements for example [3] describes the EU project *Response*: "Applied earth science mapping for evaluation of climate change impacts on coastal hazards and risk across the EU". The methodology employs commonly available digital data sets in GIS to assess regional-scale levels of coastal risk through production of series of maps. The outputs of the methodology comprise factual data maps and thematic maps and non-technical summary maps as planning guidance.

An on-going EU project is the KULTU-Risk project [4]. It will focus on water-related hazards. In particular, a variety of case studies characterised by diverse socio-economic contexts, different types of water-related hazards (floods, debris flows and landslides, storm surges) and space-time scales will be utilised [4].

In the UK there is a Climate Impact Programme (UKCIP) that contains a range of tools, methods and guidance which can be used for climate adaptation. The programme demonstrates how and where they fit into a risk-based planning process. There is also a National Appraisal of Assets and Risk from Flooding and Coastal Erosion, with adaption options on [5].

In France Baills et al. [6] have developed a method for integrating climate change scenarios into slope stability mapping. The climate factor treated as a variable in the stability calculation is the ground water level. Ground water levels are calculated from a conceptual hydrological model driven by rainfall data, and are described as filling ratio of the maximum ground water level [2].

## 3 THE SGI DECISION PROCESS MODEL FOR NATURAL HAZARDS

The SGI decision process model describes the potential risk related to a particular natural hazard, and makes it possible to establish a decision basis for spatial planning and climate adaption of built-up areas [7].

The model is partly based on the results of the Interreg Messina project [8] and the EU Life Environment Response project [9]. The model is based on identifying the prerequisites or probability for a natural hazard (P) combined with its associated consequences (C) which will determine the risk (R = PxC). The entire model can be used or only parts of it depending on the situation. The model aims to provide outcomes in the planning process that contributes to sustainable development including risk, environment, economy and social sustainability aspects as shown in Figure 1 [2].

At every stage in the decision process model (Figure 1), more detailed tools/models or suggestions exists that help to handle the questions that arise. For example under potential hazards the output can be a hazard map, and under the stage potential risk areas the output can be a risk map. Other relevant tools for identifying and assessing risk mitigation strategies can be databases or other information on previous experiences of strategies including pros and cons. It could also be a description on functionality and related costs for investment. In the long-term perspective, it could also be more holistic assessments such as life cycle and multi-criteria analyses. If there exists for example a mapping tool/model in another country it can be used instead of the one in this paper, and the other stages in the decision process model can be used together with that method.

For possible measures in spatial planning, or for adaptation of the built environment, socio-economic analyses and environmental assessments could be carried out. National and regional inventories of the natural hazards are necessary for spatial planning, to get an overview of risk areas or making priorities for preventive measures. At the local level the SGI tool can be used as a base for spatial planning, decision making of alternative measures in a municipality or at a specific location. The tool can also be used before investments are made in an area.

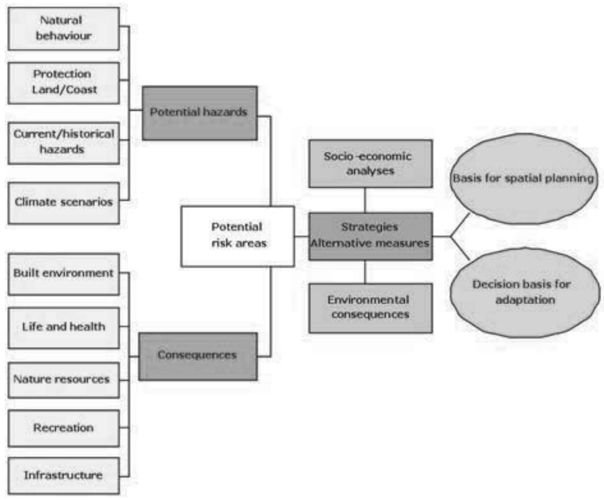


Figure 1. SGI decision process model.

Input to the model is for example Information on the site specific natural behaviour conditions which determine events that may lead to natural hazards. They can be topographical, bathymetrical, geological, water and wind conditions as well as vegetation. The high and low water levels in the sea and watercourses are important to determine. For water courses, also the streaming conditions must be estimated. These parameters are important to consider also for new climate scenarios. Also other input to the model has to be considered according to Figure 1[2].

### *3.1 Mapping of potential hazards/Probability*

The susceptibility as an indication of the *probability* of hazards such as erosion, landslides and flooding can be estimated. In Sweden, national overview investigations of landslides, erosion and flooding are carried out and described briefly below.

The Swedish **landslide hazard mapping method for fine grained sediments** (clay and silt), is used in a nation-wide programme for landslide risk reduction in built-up areas administered by the Swedish Civil Contingencies Agency (MSB). The mapping method is divided in several stages which get more detailed and need more information for each stage. Initially a pre-study is carried out, with the purpose to identify sub-areas considered to be mapped. Thereafter, the mapped areas are divided into areas with and without prerequisites for initial slope failure. The next stage is to identify areas with satisfactory stability based on overview assessment and areas that need more investigations. The results are presented in a susceptibility map with three different zones. Other information of interest for slope stability, such as calculated sections, scars of old landslides, erosion in progress and the presence of quick clay can be shown on the same map [2, 10].

There is also a Swedish **landslide hazard mapping for till and coarse soils** [2, 11, 12] administrated by MSB, divided in stages in the same way. The susceptibility for landslides and debris-flows in slopes is carried out based on a combination of overview stability calculations (safety factor) and other influencing factors. The susceptibility for debris flows in gullies is based on already occurred debris flows and by mapping and compiling factors that could contribute to triggering of a debris flow. For both cases there is in general a combination of six main factors: topography, hydrology, soil conditions, land use, earlier soil mass movements and existing preventive constructions. It is necessary to calculate the peak discharge, determine the run-off conditions, the precipitation and the amount of available soil material. A classification is made and the results of the mapping and classification are reported on a map.

A **mapping for coastal areas** can also be performed. The hazards are identified by evaluation of the present state of the coast and a coastal geomorphologic model can be established. This includes the geomorphology, the topography and bathymetry as well as the driving forces such as water levels, waves, water currents and existing coastal protection. With climate change scenario for the chosen time period the probability for hazards such as erosion, landslides and flooding can be estimated. In Sweden, an overview mapping of the prerequisites of coastal erosion of the Swedish coasts, larger lakes and rivers has been carried out by SGI and maps will be found at [16] A model for risk analysis has also been developed at SGI, based on the principle of carry out analysis step by step depending on the need for decision basis [14] In many countries there are on-going works with **inundation mapping** due to EU directive. In many cases the mapping is done only for today's climate, but it is important to complement it with climate change scenarios.

*3.2 Consequences*

Potential consequences of a natural hazard can be described on overview or detailed levels. Within a governmental investigation on slope stability in the Göta River, SGI has developed a detailed method to identify, map and when possible assess consequences of potential landslides throughout the studied area [15, 16].

The method comprises:

- identification of consequences
- inventory/mapping of objects that may be affected
- assessment of the vulnerability, ie the probability of a certain consequence in case of a landslide
- method for monetary assessment

Relevant factors to consider are e.g. population, property, contaminated land, transportation network, industry. Monetary valuation of the consequences and estimation of the vulnerability are performed. The work has been divided in societal consequence sectors: buildings; transport, exposure, vulnerability and life; environmentally hazardous activities and contaminated sites; water and sewage systems; nature; culture; energy and electric supply systems; trade and industry.

The consequence is set to be the product of the inventory of elements at risk, value per unit area, the vulnerability and the exposure. The result is presented in a 2D map with five consequence classes given in MSEK/ha.

*3.3 Potential risk areas*

The principle is to identify risk areas based on the probability of an event and the consequences of such an event. Depending on the need of information risk analysis can be carried out on overview or detailed levels. In the Göta River investigation five classes of probability and consequence, respectively, are combined in a risk matrix from which three classes of risk are identified (Figure 2);

- low risk level
- medium risk level (investigation required)
- high risk level (preventive measures are required).

The outcome of the risk analysis can be presented in maps covering the investigation area illustrating the extent of the three risk levels. The method has been used in practice in e.g. the Göta river valley [17].

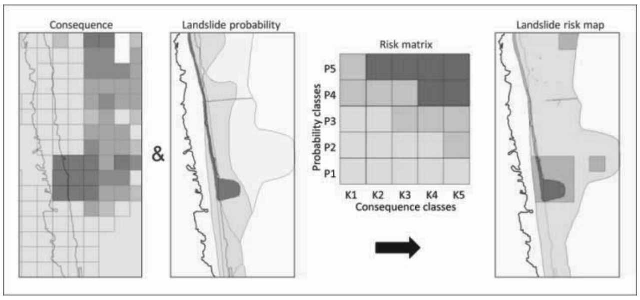


Figure 2. Illustration of risk analysis, where the consequences and probabilities for landslide are grouped into 5 classes and combined by GIS techniques in a risk matrix with three risk classes; low risk level, medium risk level (investigation required), high risk level [17].

*3.4 Strategies and alternative measures*

At the local level both for spatial planning and the built environment, the need for mitigation and adaptive measures must be identified, and data for the design and construction of such measures must be clarified. Requirements for remedial works can also be predicted using field-monitoring data, which may change the risk management philosophy from a reactive to a more pro-active one.

Mitigation measures for landslides, erosion and flooding risks often require levees, coastal protection and/or other stabilising measures. Such measures require geotechnical information during several stages of the planning and building process. In spatial planning, all factors that may cause risk for health and safety must be identified so that buildings and infrastructure will be located outside present and future risk areas or measures taken to secure these risk areas.

*3.5 Socio-economic analyses and environmental impacts*

For possible measures in spatial planning or for adaptation of the built environment socio-economic analyses are carried out. When socio-economic analyses are made they have to be based on correct actual data and valid methods to predict future development for different alternatives/scenarios. This is the basis for establishing the risk level that needs to be related to the acceptable risk level, the need of, and which, countermeasures that can be used to alleviate the potential problems. Also the stakeholders must be identified and the activities that are affected by possible changes to the land or coastal area. Analysis can be done for example by a Cost-Benefit Analysis (CBA). The basic way of working with a CBA model is to start by estimating total damage and loss for the "Do Nothing"-alternative. This value is later used as the benefit (or avoided damage) for the investigated options of preventive actions. The next step is to estimate the schedule and cost of implementing the options. Finally, if there still is a risk of damages for the investigated options; the cost of this is also calculated. For a CBA the selection criterion is that if the ratio between benefits and costs is greater than 1 (benefits divided by costs >1) the option is worth doing. The option with the highest benefit cost ratio gives "best value for money" [18].

Most of measures to reduce risks for natural hazards have to be built in environmentally and naturally sensitive areas close to the sea or rivers, in some cases consisting of Natura 200 areas. For that reason, all measures have to be evaluated due to the environmental impacts. For the proposed strategies and alternative measurements environmental consequences have to be considered.

*3.6 Basis for spatial planning and adaptation*

For spatial planning, following the stages in the model, the decision makers will have a proper and transparent basis for discussion with different stakeholders and the final decision of the best available way to establish sustainable land and coastal areas.

For the built environment, the decision makers will have a proper and transparent basis for the discussion with different stakeholders and the final decision of the best available way to adapt built environment on land and in coastal areas.

## 4 EXAMPLE ON THE LOCAL LEVEL

The model or parts of the model has been used in several climate and vulnerability analysis in Sweden, both on regional and local level.

The municipalities have to make comprehensive plans and detailed development plans, where risks for natural hazards must be investigated. In order to consider the consequences of climate change on the planned and existing built environment SGI and Swedish Metrological and Hydrological Institute have on behalf of Nynashamn municipality carried out an Overview Climate- and Vulnerability Analysis as a basis for the Municipal Comprehensive Plan 2010.

When working with comprehensive plans detailed data normally is not available, so the evaluation was made of the interface between areas with risk for natural hazards and consequences for important society constructions. The aim of the investigation was to clarify the consequences due to increased rain fall and sea level rise for different scenarios. Areas with risks for flooding, landslides or erosion have been investigated and the risk areas are illustrated in maps, see Figure 3. The interface between these areas and important society constructions has also been shown. The constructions can be e.g. special buildings, roads, railroads, dams. Environmental aspects have to be considered for e.g. flooding or landslides in contaminated areas or areas with enterprises with potential hazardous activities or dangerous substances.

An example of such a map is shown in Figure 3. The flooding from sea level rise is shown in the figure for different scenarios and the levels are also shown in Table 1.

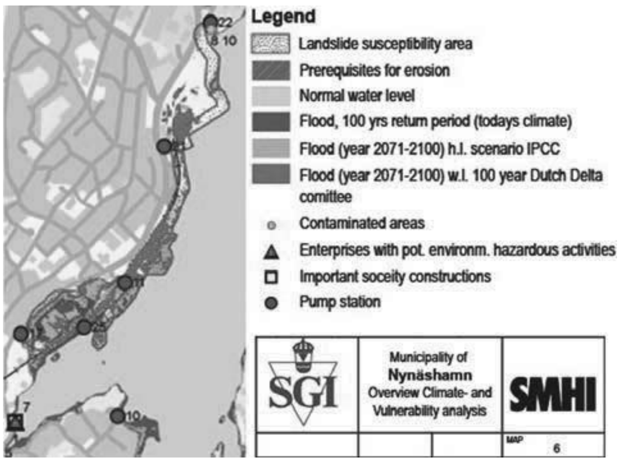


Figure 3. Part of Overview Climate- and Vulnerability Analysis for the Municipality of Nynäshamn in Sweden [2].

Table 1. The sea level for determination of flood along the coast of Nynashamn (given in meter in the Swedish height system RH00).

| Case | *Level (RH00)* |
|---|---|
| 1. Flood, 100 years return period (today's climate) | 0.68 |
| 2. Flood calculated future (year 2071-2100) high level scenario according to IPCC | 1.30 |
| 3. Flood, future (year 2071-2100) water level with 100 years return period, according to the Dutch Delta committee | 1.71 |

As shown in the figure and table there can be rather different results depending on which scenario that are used. It is important to compare different scenarios and act for uncertainties. Recommendations have to be suggested for spatial planning. In built-up areas natural risks measures have to be taken to prevent damages on constructions. Strategies and measures are suggested, for example slope excavations, berms, levees, coastal protection or other stabilising measures.

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