Forecasting rainfall-induced landslide at country level: recent experiences from El Salvador and Norway

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Introduction

The link between rainfall and the occurrence of landslides is well known and it has been used extensively for prediction of landslides around the world.

Early warning system at regional or local scale are become in recent years important tools for disaster risk reduction and for achieving sustainable development. The purpose of a landslide early warning system is to analyze, forecast and follow the hydro-meteorological conditions that possess the potential of triggering landslides. The main aim is to inform the authorities in advance, allowing stakeholders to take actions that can help to reducing the amount of casualties and physical damages.

Numerous examples of both operational and research-phase systems exist at local level, monitoring often single torrents or single slopes (Illgraben catchment, Switzerland), and some example exist at regional level (like in Liguria region, Italy; southern California, USA) or for large cities (Rio de Janeiro, Brazil) too. However very few territories count with operational early warning systems for the entire country.

El Salvador and Norway started in recent years a daily warning system for rainfall-induced landslides. Herein we summarize the procedures, map tools, models, thresholds and web communication tools used in these two countries.

Figure 1. Example of rainfall-induced landslide and damage to the infrastructure in El Salvador and Norway

Rainfall –induced landslides

Shallow soil slides, debris avalanches, debris flows (also in volcanic slopes) are yearly responsible of many casualties and significant damages to roads and railway lines, buildings, and other infrastructures in many countries around the world, differently located in latitudes and exposed to climatic conditions.

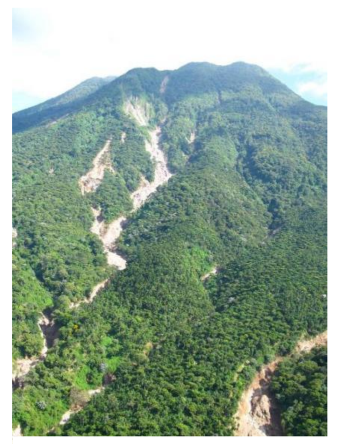
Intense rainfall (prolonged or short) is the main triggering mechanism of these landslide types. In countries located near the tropics, like El Salvador, intense rainfall are commonly associated to Atlantic or Pacific tropical cyclones or to normal convective cells. In countries located in northern latitudes, like Norway the most intense rainfall are associated to low pressure systems that form in the Atlantic, sometimes associated to remnants of tropical cyclones (also known as extra-tropical cyclone) that usually form in the Caribbean area. However, here also intense and rapid snowmelt or a combination of both rainfall and snow melting can be a significant trigger.

In low-income and high densely populated countries most of the losses associated to these landslides are mainly human losses, while in high-income and less populated countries they are mainly associated to the infrastructure, observing rarely human losses. In both case the total amount of losses is high and hamper the normal economical development of a country or of a region.

El Salvador

Organization

The Landslide Monitoring Center of the Ministry of Environment and Natural Resources/General Directorate of the Environmental Observatory (MARN/DGOA) has a landslide early warning system that has been operational since 2010. The centre works 24/7 and uses primarily a network of 130 rain gauges to evaluate the landslide susceptibility conditions in the country. The center is integrated with the areas of meteorology, hydrology and seismology, through the Natural Hazards Monitoring Center.

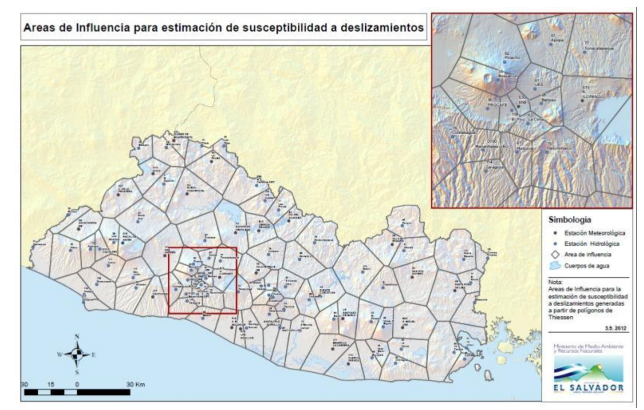


Volcán de San Vicente, 2009

Model and Data

Rain gauges are distributed country-wide. The density is higher in the metropolitan area of the capital city, San Salvador. 75 of these rain gauges transmit data via satellite in near real-time. Thiessen polygons are used to assign precipitation to each rain gauge. Everyday a landslide susceptibility evaluation is conducted using all the gauges, and a daily report is generated.

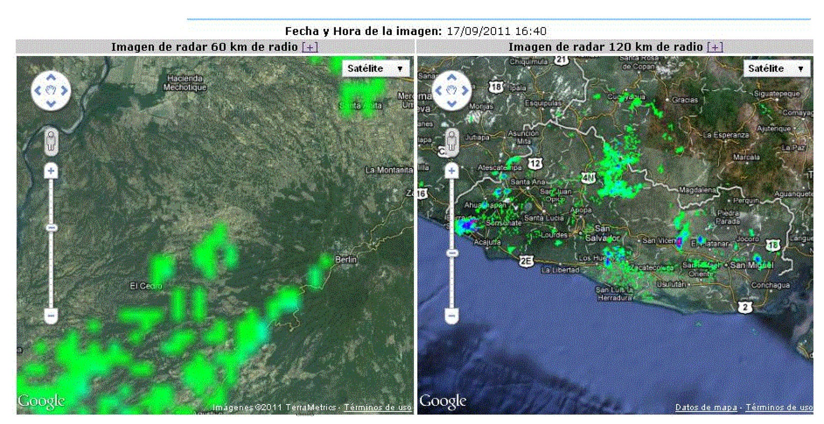
For real-time evaluation, only the automatic rain gauges are used.



Thresholds

The thresholds used are based on the accumulated rainfall of 24 hours, 4 days and 15 days. The thresholds were created with historical records of rainfall-triggered landslides in El Salvador. For each accumulated rainfall period (1, 4 and 15 days) there is a threshold, and a weight is assigned for each period, according to a scale. The sum of the weights is then reclassified in a susceptibility index. For real-time evaluation, the thresholds are diferent, and the rainfall intensity is also monitored.

The use of other models based on satellite-based precipitation and the improvement of the model used for the evaluation of landslide susceptibility is a research in progress.

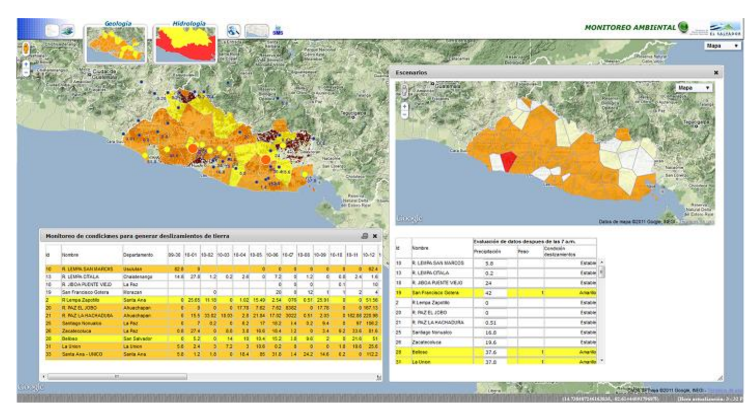


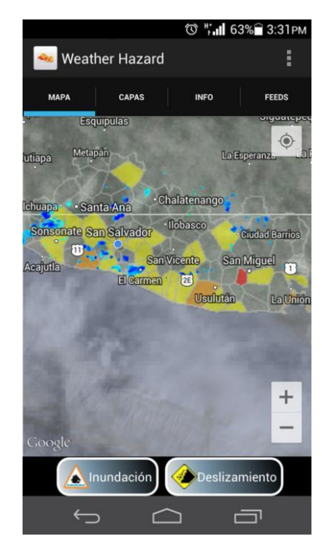
Other tools used for monitoring

The DGOA/MARN also has a network of 8 X-band radars, for short-term forecast. The radars have a 60 km range and provide images of rainfall every 5 minutes. If intense rainfall is observed in the radar in a specific zone, the information is traslated to Civil Defense.

Web application

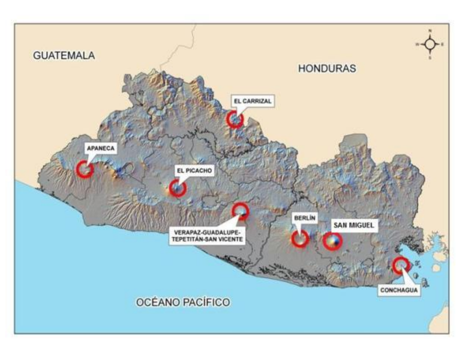
The model and thresholds used are automated in a web application, which shows both flood and landslide susceptibility conditions. The application retrieves the data from the automatic rain gauges and classifies the Thiessen poligons in four categories: Stable, low, medium and high. Colors varying from white to the lowest category to red to the highest are assigned to each polygon. There is also a mobile app of this application called «Weather Hazard», available for the Android mobile operative system.





Critical zones

There are some critical zones for monitoring, in which landslides have been frequent historically. Special attention is given to them. There are also vounteers in this zones, some of them with manual rain gauges, that provide data when needed and assist Civil Defense with the early warning system.



Communication chain

The daily reports and real-time changes in landslide susceptibility are informed to Civil Defense. If the meteorological forecast foresees critical conditions, a special report is emitted. All this information is also broadcasted to the MARN web page and social networks.

Norway

Organization

The Hydrological Department of the Norwegian Water Resources and Energy Directorate (NVE) operates regional early warning systems for flood, rainfall-induced landslides and snow avalanche. The landslide and flood early warning system work in sinergy sharing same meteorological and hydrological observations, forecasts, tools and organization of personnel, and economy. The warning service is nationwide and operated 24 h/7day by a multidisciplinary team (~23 among hydrologists and geoscientists, 12 women and 11 men, age from 30 to 59 years). The total annual cost for flood and landslide forecasting services: € 1.4 mill (Includes forecasters compensation, research & development, management, etc.). While the flood services is operational since 1989, the landslide service, herein presented, is operational since October 2013.

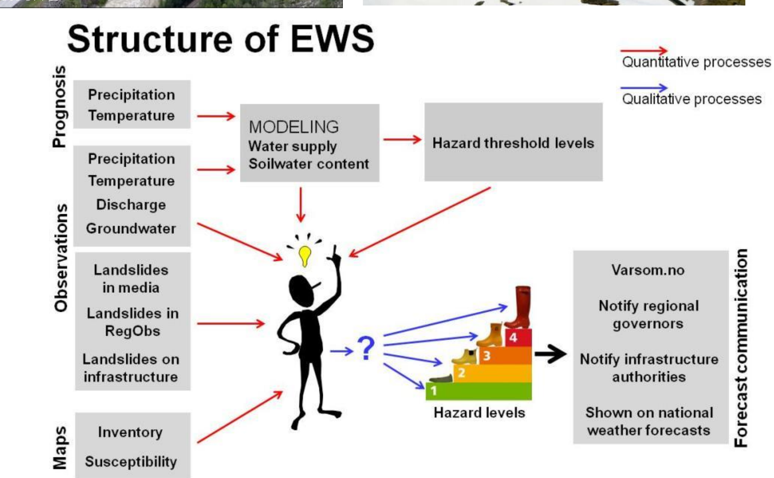
Type of landslides

The system is developed to warn shallow soil slides, debris avalanches, debris flow and slush flows.

Structure

It is based on weather forecasts and information about hydro-meteorological conditions that are derived from real-time measurements, model simulations and ground condition forecasts.

Structure of EWS



Available real time measurements:

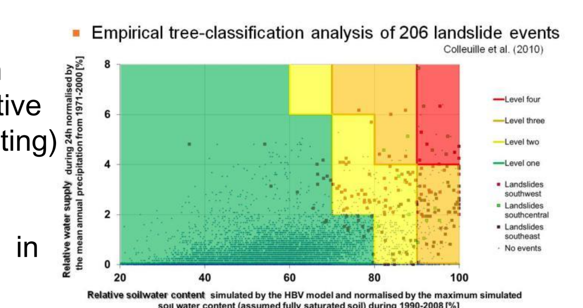
- Meteorological data (NVE, met.no, SVV, JBV)
- River discharge (350)
- Groundwater level (80)
- Soil water content and soil temperature (17)
- Snow water equivalent (25)
- Traffic reports recording closures of road because of landslide events
- Historical landslide data (from landslide database) and recent events from real-time database

Models and maps

Distributed hydrological HBV-model, 1 km² grid cells use discharge observation, prognosis on temperature and precipitation to obtain different simulated parameter like snow water equivalence and snow depth, soil water content, ground water content, soil frost depth, etc.
Landslide susceptibility maps at catchment level are used as support maps during the daily evaluation but also combined with the dynamic maps of the thresholds to improve the spatial distribution of the thresholds

Landslide thresholds

Are based on relationship between relative soil water content and relative water supply (rainfall and snowmelting) but others variable are under investigation. Thresholds are represented in from of graphic and in form of dynamic maps.



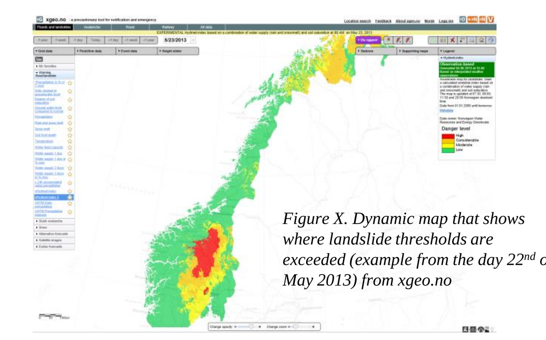


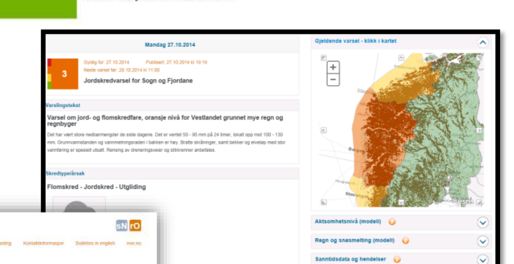
Figure X. Dynamic map that shows where landslide thresholds are exceeded (example from the day 22nd of May 2013) from xgeo.no

Expert tools

Xgeo.no : the system uses a web portal, developed and maintained by NVE since 2008. This is a map centric tool for visualization of temporal and spatial data, management of large amount of real-time measurements and simulations from various sources. Combines observations, model results and threshold values.
regObs.no: assure a continuous field observations submitted in a real-time database, enabling a better overview of hydro-meteorological conditions.

Communication chain

Warning messages are published at **Varsom.no** . The communication of the risk is rapidly distributed to authorities, risk-managers and the population.



Recent experiences

Since operational the landslide early warning system was able to predict important landslide events like in May 2013 in south-Eastern Norway, October 2014 in western Norway.

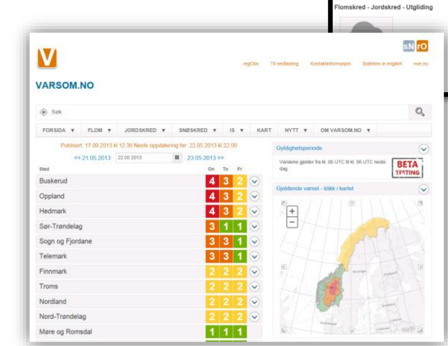


Figure X. Example of warning message published at Varsom.no: left, entire country; over, zoom at regional level