Decision Support Tool in the Project LANDSLIDE

Nina Dobrinkova and Pierluigi Maponi

Abstract In the framework of the LANDSLIDE project has been fulfilled field work on the test areas in Bulgaria, Italy, Poland and Greece. The project goal is to create a software tool helping the decision makers in cases of landslides with up to 20 m depth which can estimate the soil movement by calculating soil moisture and meteorological data conditions which in the literature are considered as main triggers in such natural hazards.

Keywords Landslide hazard · Soil moisture · Limit equilibrium analysis

1 Introduction

The project LANDSLIDE risk assessment model for disaster prevention and mitigation (acronym: LANDSLIDE) is a European project, co-financed by the Directorate General Humanitarian Aid and Civil Protection of the European Commission, with the aim to develop an innovative risk assessment tool to predict and evaluate landslide hazards. The project is with duration 24 months starting from 1st January 2015 and ending on 31st December 2016. The project has been proposed, because landslides occur in many different geological and environmental settings across Europe and are a major hazard in most mountainous and hilly regions [1]. Every year landslides cause fatalities and large damage to infrastructure and property. One of the reasons land-slides to activate its potential is intense or long lasting rainfalls. This is the most frequent trigger of landslides occurrence in Europe [2], and is expected to increase in

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the future due to climate change. Methods for landslide hazard evaluation are today mainly based on scientific literature of geomorphologic studies and of historical landslide events, see [3, 4] and the references therein for an example; these studies do not consider or underestimate the impact of climate change. Therefore, it is important that interdisciplinary approach for landslide monitoring and prediction between the nowadays ICT (Information and Communications Technology) solutions and landslide experts has to start. This cooperation is useful in order to provide new tools that can adapt to the new conditions by correctly evaluating and predicting landslide hazards which is a fundamental prerequisite for accurate risk mapping and assessment and for the consequent implementation of appropriate prevention measures.

A physical approach to this problem can be based on the so-called Limit Equilibrium Analysis and the Mohr-Coulomb relation for the shear strengths of the materials along the potential failure surface, see [5] for details. However, the practical application of this theory to the landslide hazard evaluation requires the knowledge of soil moisture. The main scientific contribution of the project is given by a new procedure to evaluate landslide hazard level, where the main components are the soil moisture dynamics and the slope stability analysis. This physics-based procedure allows the evaluation of the hazard level directly from weather forecast data. The resulting hazard evaluation system works in continuous-time and provides hazard maps every daily. These maps depend on the relevant geomorphological features of the test area and of the weather data, so the statistical analysis of a long series of such maps may also provide the impact of climate change on the study area.

The LANDSLIDE project, coordinated by the University of Camerino, is made up of 6 partner organizations coming from Italy, Bulgaria, Greece and Poland:

- University of Camerino (project Coordinator), Italy
  - Institute of Information and Communication Technologies—Bulgarian Academy of Sciences, Bulgaria
  - National Observatory of Athens—Institute of Geodynamics, Greece
  - Province of Ancona, Italy
  - Regional Government of Smolyan, Bulgaria
  - Bielsko-Biala District, Poland

This partnership aims jointly to develop a Landslide Hazard Assessment Model that will be tested in four hydrographic basins selected as test sites. This model and software will be able to make completely automatic predictions of landslide hazards which may occur in soil up to 20th meter depth. The predictions can be automated on a day to day basis, as well as to correctly evaluate the impact of climate change, in a medium long term. The system, which is still under development, focus on landslides with dept up to 20 m, because the meteorological conditions usually influence on such landslides. Deeper soil anomalies are thought by literature as more complex than just weather conditions driven natural hazards.

2 Description of the Dynamic Evaluation of Soil-Moisture Content in LANDSLIDE Project Software Tool

The main components in the method for the computation of landslide hazard are: the soil moisture dynamics and the slope stability analysis. The following subsections give a detailed description of these two components.

2.1 *Soil Moisture Dynamics*

The dynamics of soil-moisture content is a complex phenomenon depending on atmospheric conditions, geological features of the region under study, and the corresponding land use. It can be formally described by diffusion equation models arising from Darcys law, and mass continuity law. These models depend on several parameters that should be chosen on the basis of the geological features of the region under study. When these parameters are set, a numerical approximation method must be used for the computation of the soil-moisture dynamics from the weather data inputs. This model is usually called the Richards equation:

$$\left(C(\psi) - S\frac{\theta(\psi)}{n}\right)\frac{\partial h}{\partial t} = \nabla\left(K(\psi)\nabla h\right) + W(x, y, z, t) - ET(x, y, z, t),$$
$$(x, y, z) \in B,\ t > 0 \qquad (1)$$

where $h = \psi + z$ is the hydraulic head and ψ is the pressure head, K is a diagonal matrix describing the hydraulic conductivity, which measures the ability of water to flow in the porous isotropic medium, C is the specific moisture capacity, S is the storage coefficient, n is the porosity of the soil, W is the recharge and it is related to the rate of precipitation, ET is the evapo-transpiration and it represents the loss of water due to the evaporation and transpiration of plants. Note that in (1) appears also function θ, that is the water content of the soil; it can be computed from the pressure head ψ through the Van Genuchten formula [1]. So, the soil moisture content θ can be obtained from the knowledge of the solution h of the Eq. (1). See [2, 6] for a detailed description of the Richards equation. The spatial domain B, where Eq. (1) is defined, gives a three-dimensional description of the basin under study. In particular, B is given by a slice of soil beneath the slope under study; so, the boundary ∂B of B is constituted by a top surface S_T, describing the soil surface, a bottom surface S_B describing the depth where the soil moisture content is analyzed, and a vertical surface S_V joining the boundary of S_T and S_B. The two source terms W and ET appearing in Eq. (1) depend on the weather data and on the land use. These functions have a narrow support that extend beneath top surface S_T; moreover, W is computed from the precipitation data, and ET from the so called Penman-Montieth equation [6], that gives an evaluation of evapo-transpiration by using vegetation data and weather data. Appropriate initial-boundary conditions must be considered with Eq. (1) in order to define a unique solution h, see [2] for details. The resulting initial-boundary value problem constitutes the proposed model for the soil moisture dynamics. The numerical solution of this problem is computed by a finite difference method resembling the well-known Cranck-Nicolson method for diffusion problems, see [3] for details.

2.2 Slope Stability Analysis

This analysis must give an evaluation of the resistance of inclined surfaces to failure by sliding or collapsing. The hazard degree can be expressed by the factor of safety F, which is the ratio between the forces that prevent the slope from failing and those that make the slope fail; the Mohr-Coulomb criterion [4] is used for this evaluation. Of course, when the factor of safety is less than one the slope should be considered unstable. Different methods can be used for the evaluation of F. The Infinite Slope Model is probably the simplest possible method: the soil surface is approximated by an infinite inclined plane. In this case the following approximation of F can be obtained:

$$F = \frac{C + (z\gamma - z_w\gamma_w)\cos^2(\beta)\tan(\phi)}{z\gamma\sin(\beta)\cos(\beta)} \tag{2}$$

where C is the effective cohesion, γ is the weight of soil, γ_w is the weight of water soil, z is the depth of failure surface, z_w is the depth of water table, β is the slope surface inclination, ϕ is the angle of internal friction, [4] for details. The factor of safety F can be easily computed from formula (2) in every point of the slope under study. In the LANDSLIDE project this is used as a first estimate of the landslide hazard index, that is automatically produced by the software tool. The corresponding risk map is delivered to the competent territorial authority, that, on the base of this map, can also require a more detailed analysis on small portions of the slope under study. The accurate estimation of the factor of safety F is obtained by a three-dimensional version of the method of slices. In this method the slab of soil beneath the slope is discretized by several vertical columns, where it is considered the forces equilibrium and the corresponding moments equilibrium along the three coordinate directions. For sake of brevity a detailed description of this method must be omitted, however an exhaustive explanation of the method of slices is provided in [7].

3 Test Beds in the Project LANDSLIDE

The areas where the software developed under the project LANDSLIDE is going to be tested and validated are located on the territories of Greece, Italy, Bulgaria and Poland. Short descriptions and fulfilled work in order the software requirements to be implemented will be briefly introduced.

The first test area is located on Peloponnesus peninsula in Greece. The responsible partner for that area is the National Observatory of Athens (NOA) implementing all LANDSLIDE activities. Peloponnesus is a very mountainous area with over 1,000,000 inhabitants, including also remote villages at risk of landslides. The territory is administratively divided between the Region of Peloponnesus with Tripoli as the capital city and the Region of Western Greece with Patras as the capital city. The area of Panagopoula was chosen as the test site, because past landslide events have cut rail and road connection from the Greek capital Athens to Patras for weeks. Patras is the most important port of western Greece. At the moment new rail and road connections from Athens to Patras (co-financed by European Union) are being constructed under Panagopoula as the morphology of Northern Peloponnesus does not allow any alternatives. Any major landside event may have tremendous consequences for the economy of western Greece. The Panagopoula landslide area is situated in the northern part of the Prefecture of Achaia (northwestern Peloponnesus, about 15 km east of Patras). NOA has selected the pilot area very carefully. All measurements on the field have been completed and 10 GIS maps were elaborated. To correctly collect data, a meteorological station has been acquired and installed in a safe position and started transmitting data in real time in the weather meteorological stations network of NOA.

The second test area is located in Province of Ancona Italy. The pilot area selected for the test and implementation of the LANDSLIDE model and software in Italy is a hydrographic basin of 11.69 sq. km located in the mid part of the Esino River basin (i.e. in the central part of the territory of the Province of Ancona). The test area was chosen as it is representative, also of the other hydrographic basins of the Province of Ancona: in effect about 30 % of the whole test area is concerned by landslides (i.e. 3.55 sq. km) and a landslide has recently damaged and interrupted the provincial road connecting 3 municipalities. Furthermore, several meteorological stations are located in the test area and previous geological and geotechnical studies have already been carried out. Having identified the hydrographic basin, drilling and sampling operations are being implemented according to the protocol agreed among project partners, as well as geological and geomorphological data of the area, are being collected to elaborate GIS maps. It is crucial to note that more than 300 sq. km (15.6 % of the whole provincial territory) are afflicted by landslides. According to the Basin Authority of the Marche Region: out of a total number of 18815 landslides that occurred on the territory of the Marche Region, 5676 are landslides occurred only in the Province of Ancona. The worst landslide ever occurred on the territory is the so called Ancona big landslide, a very large and deep soil movement (slipping surface was identified more than 100 m deep in the Pliocene clays) collapsed on 13th December 1982 after a very rainy period. The area concerned by the landslide, affected and damaged two hospitals, one university building, 280 houses, the railway and more than 2.5 km of the main Adriatic road. 3661 people were evacuated.

The third test area used by the project model and software is the Smolyan Region in Bulgaria. The hydrographic basin selected for the test and implementation of the LANDSLIDE project in Bulgaria is a landslide called "Smolyan Lakes". It is located northwest of the town of Smolyan. Its borders match the Kriva River to the west, Muneva River to the East, Cherna River to the South, and the steep rock cliff, which is located south of the peak Snejanka. The length of the landslide is 5.35 km, average width—1.38 km and the depth of the landslide area—35–80 m. Its total area is 7.4 sq. km. The biggest landslide in Bulgaria was registered in 1923. It is located in the western suburbs of the very town of Smolyan. It has a width of 1 km and length of 5 km. It is active, with speed of movement of 5–25 cm per year. Its depth is 80 m. The landslide is moving slowly, however if no measures will be taken it could affect the main road of the Region, disconnecting the access to Smolyan. Smolyan Region covers an area of 3192 km^2, it has a permanent population of 120,456 people and is located in South Bulgaria in the central part of the Rhodope Mountains. The regional territory is characterized by mountains and several landslides occur every year; in effect, 87 landslides have been registered and one of these is the biggest landslide ever occurred in Bulgaria.

The fourth test area is located in Poland called Bielsko-Biala District. The hydrographic basin has been set within the Small Beskid mountain range, and field studies are taking place in an inactive sandstone quarry in Kozy. Landslides are among the most common geodynamic threats, often having the characteristics of a natural disaster. The floods which occurred in the southern Poland throughout the last 20 years resulted in the fact that many residents of the cataclysm area were affected by the phenomena of landslides combined with various losses (area degradation, destruction of residential buildings together with road network, sewerage system, telecommunication lines, electric lines, gas pipelines, crops and forests). The first deformation processes within the Small Beskid area were already registered in 1968 in the quarry located in Kozy. The surface mass movements have been a continuous phenomenon, and their development have been constantly observed. In 2010 a total number of 437 landslides were registered (active, periodically active and inactive). Bielsko-Biala is located in the southern part of Poland, in the province of Silesia. Geographically, it is located in the eastern part of the Silesian Foothills of the outer part of the Western Carpathians, and in terms of morphology it is situated in the massif of Small Beskid and Silesian Beskid mountain ranges. In the area of Bielsko-Biala District, can be observed numerous mass movements, which is part of the responsibility of the Head of a district.

4 E-platform Architecture and Design in LANDSLIDE Project

During the first year of the project lifetime the team from IICT-BAS has started collection of all data in one GIS database. This was done in order the model developed by the University of Camerino in Italy to be able to start validation and tests of its functionalities. The software development is following the description of the Fig. 1 workflow.

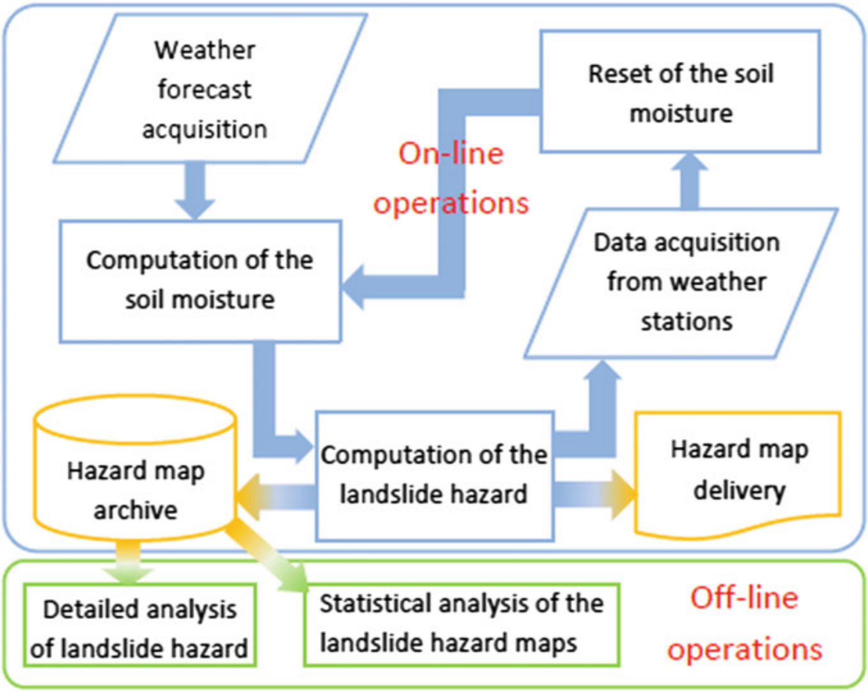

Fig. 1 Data flow in the computational system

The data processing in the system a continuous-time system, where every day gets the weather forecast data (for the next 24 h); from these data, computes the soil moisture content and the corresponding Safety Factor by the using Infinite Slope Model, that is used to create the landslide hazard maps; at the end of the day, the system acquires the weather data from the weather stations on the territory and refines the soil moisture content. Then it restarts the forecast procedure by taking into account the weather forecast data for the next day. An off-line functionally is also provided. This is mainly composed of two facilities: (i) a refined analysis of the hazard level by using a three-dimensional version of the method of slices, (ii) a statistical analysis of the hazard maps.

The main actors are divided in three general groups in the system. The first group is dedicated to users from the project, the second is dedicated to the GIS administrators of the system and the third which is public is oriented to the WEB users of the system. The system architecture is made in a way that the WEB site can dynamically generate map content and present any kind of spatial data or attribute query for it. The architecture is done in a way to be compatible with any kind of platforms (UNIX, Windows etc.), with J2EE compliant server. The tool can be run on any JAVA enabled Internet browser or standalone, on any platform with JRE 1.1.8 or greater for SUN Microsystems.

5 Conclusion

The project LANDSLIDE has been done in a way that the partners developing the model and the software work very closely with each other. The end user partners from Greece, Italy, Bulgaria and Poland will have more than 6 months for testing and validating the final tool developed by the teams of University of Camerino and IICT-BAS. The project lifetime is 2 years starting from January 2015, but all achieved results under the project in the end of 2016 can be a step forward towards better civil protection in cases of landslide hazards up to the 20th meter of soil layers movements.

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