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LEWIS Project: An Integrated System for Landslides Early Warning

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Abstract

In the framework of the National Operational Programme 2007-13 "Research and Competitiveness", co-funded by the European Regional Development Fund, the Ministry of Research (MIUR) financed the project "AN INTEGRATED SYSTEMS FOR HYDROGEOLOGICAL RISK MONITORING, EARLY WARNING AND MITIGATION ALONG THE MAIN LIFELINES" with the acronym LEWIS (Landslides Early Warning Integrated System). The project aims to develop an integrated, innovative and efficient solution to manage risk issues associated with infrastructure, on landslide-prone slopes by developing and testing a system able to identify potentially dangerous landslides in a timely manner, and to activate all needed measures for impact mitigation, including information delivery. The system includes many components: standard criteria for evaluation and mapping landslides susceptibility: monitoring equipment for measuring the onset of landslide movement; telecommunication networks; mathematical models for both triggering and propagation of landslides induced by rainfall; models for risk scenario forecasting; a centre for data acquisition and processing; and a traffic control centre.

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Landslide forecasting · Early warning systems · Risk scenarios

Contents

1 Introduction

In areas where landslide risk is very high and financial resources are scarce, an integrated approach that combines structural and non-structural measures and a complex strategy is necessary. It includes qualitative and quantitative risk analysis, monitoring, advanced early warning systems, mathematical modelling of rainfall-landslide relationships, decision-making procedures, a strategy for risk reduction measures, and plans for emergency management, works and maintenance.

In recent years, attention has been focused more and more on early warning systems, by developing both single components and integrated systems (Sassa and Yueping 2010). An early warning system aims to ensure the provision of timely and effective information that allow exposed people to make decisions in order to avoid or reduce damages and the loss of life (Intrieri et al. 2013). The safety actions are efficient when they are developed during the "lead-time", that is the time interval between the moment of the event prediction and the moment of the landslide impact.

A landslide early warning system, in its general configuration, should include landslide susceptibility maps for the investigated areas, scenarios for the impact of the events on exposed people and goods, monitoring of key parameters, real time data transmission, mathematical models and data processing for both current hazard evaluation and future hazard forecasting, a warning model, an emergency plan in order to avoid or reduce the damages and the loss of life, and a decision-making procedure.

In the design of these systems the velocity of the expected landslides plays a very important role; as it affects not only landslide destructiveness but also the procedures for risk mitigation, as velocities can range from some tens of meters per second to some millimetres per year.

From a general point of view, there are four crucial moments in landslide early warning systems: precursor forecasting (t_1), precursor occurrence (t_2), event onset (t_3) and impact on people and goods (t_4).

Early warning systems are quite efficient when the lead-time, corresponding to the time interval (t_4–t_3) is sufficiently long to make decisions and take actions such as evacuation or protection of structures and infrastructures. When the time between the event onset and its impact (t_4–t_3) is extremely short, the early warning procedure must be based on precursor measurements, when possible. This is the case for rapid landslides, as the time elapsing between the onset of slope failure and its impact on exposed goods is typically in the order of tens of seconds or a few minutes. When the time between precursor occurrence and event onset (t_3–t_2) is also short,

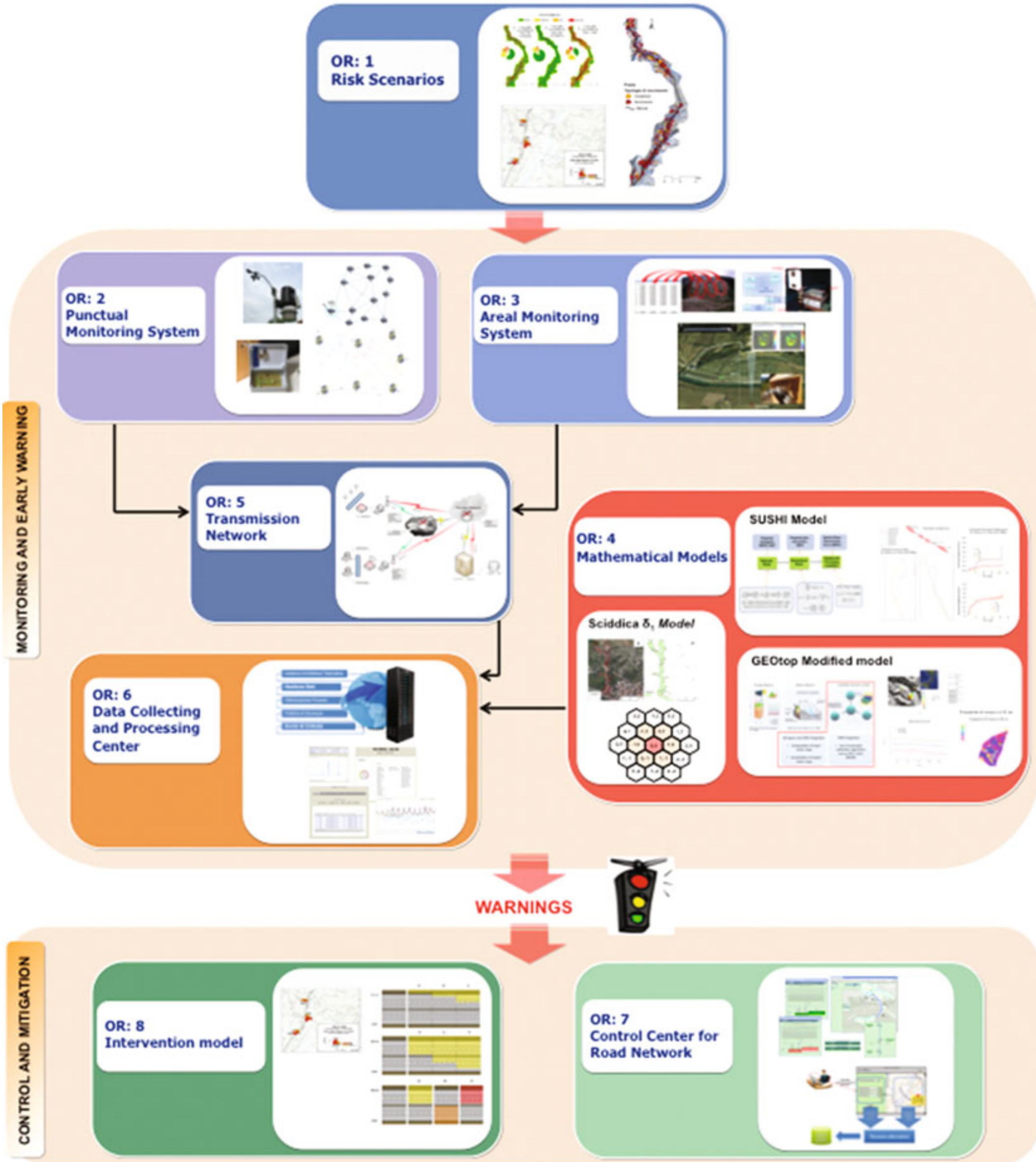


Fig. 1 Interrelation among the different research components

the forecasting of the precursor becomes essential. This is the case for shallow landslides, for which the difference (t_3–t_2) is in the order of tens of minutes or few hours. Then, depending on the landslide velocity, the system can address movement detection for “slow” landslides or forecasting, with mathematical models, the movement onset for “rapid” landslides.

This teaching tool describes an integrated system for landslide early warning that considers both slow and rapid movements, develops original components and integrates them in a flexible system that can be adapted to different environments. Moreover, it also considers rainfall forecast for landslide trigger. In other cases, early warning systems can be only based on measures of displacements, which cannot be forecasted.

In the framework of the National Operational Programme 2007-13 “Research and Competitiveness”, co-funded by the European Regional Development Fund, the Ministry of Research (MIUR) financed the project “An Integrated System for Landslide Monitoring, Early Warning and Risk Mitigation along Lifelines”, with the acronym LEWIS (Landslides Early Warning Integrated System).

The project includes industrial research, at site tests and training activities, with a two-year master programme at postgraduate level. The system includes many components: standard criteria for evaluation and mapping landslide susceptibility; monitoring equipment for measuring the onset of landslide movement, telecommunication networks, mathematical models for both triggering and propagation of landslides induced by rainfall, models for risk scenario forecasting, a centre for data acquisition and processing, and a traffic control centre.

In Fig. 1, a flow chart showing the interrelation among the different research components is outlined. The integration of the system allows for maximizing its operational flexibility, as each developed component provides different interchangeable technological solutions. Therefore, the final system may assume many different configurations, from the simplest to the most complex, to deal with different scenarios. The flexibility essentially depends on the wide range of monitoring equipment, both traditional and innovative, that have been considered and on the different kind of mathematical models that have been developed. In particular, six monitoring schemes are adopted here: three point-measuring systems, made up of a network of sensors that locally measure the start of shallow or deep displacements, and three area-measuring systems that remotely measure the movement of large slopes. All the monitoring systems are fully integrated and are connected to the same data transmission system. Concerning the mathematical modelling for landslide triggering, the system includes both empirical and complete models. The empirical or hydrological models are simple relationships, obtained by linking the antecedent rainfall and the occurrence time of a landslide. On the other hand, the complete models take into account the hydrological and geotechnical processes involved in slope scale and that affect stability. The complete models, adopted in this research, include local models and areal models.

Standardized and shared procedures for the identification of risk scenarios, for surveys to be carried out, for procedures for each type of on-site testing, for data assimilation techniques, for presentations of results, such as maps of risk along a highway, landslides susceptibility maps and so on, are the bases for the compactness of the whole system.

The setting up of the data acquisition and processing centre and of the traffic control centre are the core of the integrated system. The CAED (“Centro Acquisizione ed Elaborazione Dati”—Data Collecting and Processing Center) acquires

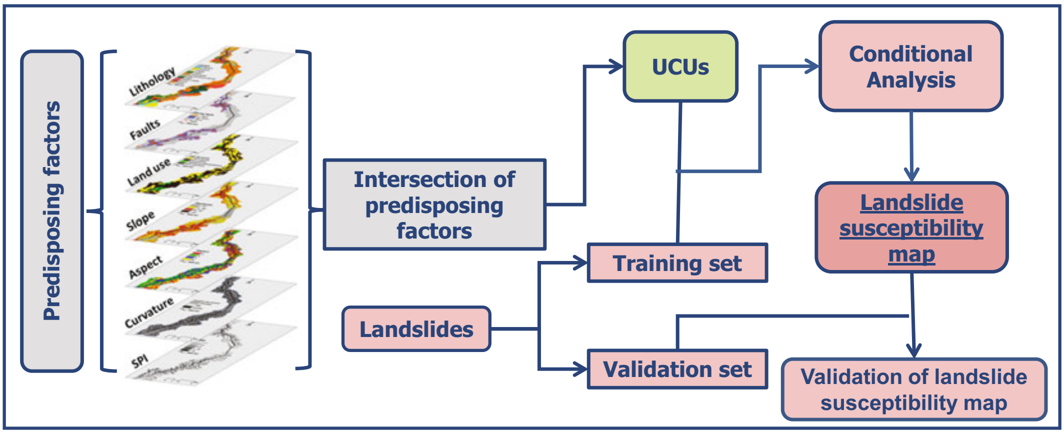


Fig. 2 Flow chart showing the landslide susceptibility method

and processes data that are tremendously variable in intensity, dimensions, characteristics and information content. The Control Center for Road Network (CCC) is meant to integrate the scientific and the management aspects of hydrological risk monitoring and early warning.

Tests for experimentation and validation of the system have been carried out in three highway segments, related to Campania, Puglia, Calabria and Sicily, which are Italian Regions interested in the Community Support Framework.

In the following chapters the LEWIS components will be described:

- Landslide susceptibility assessment;
- Displacement measurement;
- System for displacement forecasting;
- Data transmission network;
- Data Collecting and Processing Center (CAED);
- Control Center for Road Network (CCC);
- Intervention model.

The last topic is developed in greater detail (see also Versace et al. 2014). In fact, the intervention model is an important component for the correct functioning of an integrated system such as the one here described, which must combine the information coming from different sensors and models.

For the sake of brevity, experimental sites, and the related results, are not described in this teaching tool. For more details, please visit the website www.camilab.unical.it.

2 Landslide Susceptibility Assessment

In this study, the predisposing factors were selected from the most commonly used in literature (VanWestern et al. 2008) and based on the geological and geomorphological settings of the

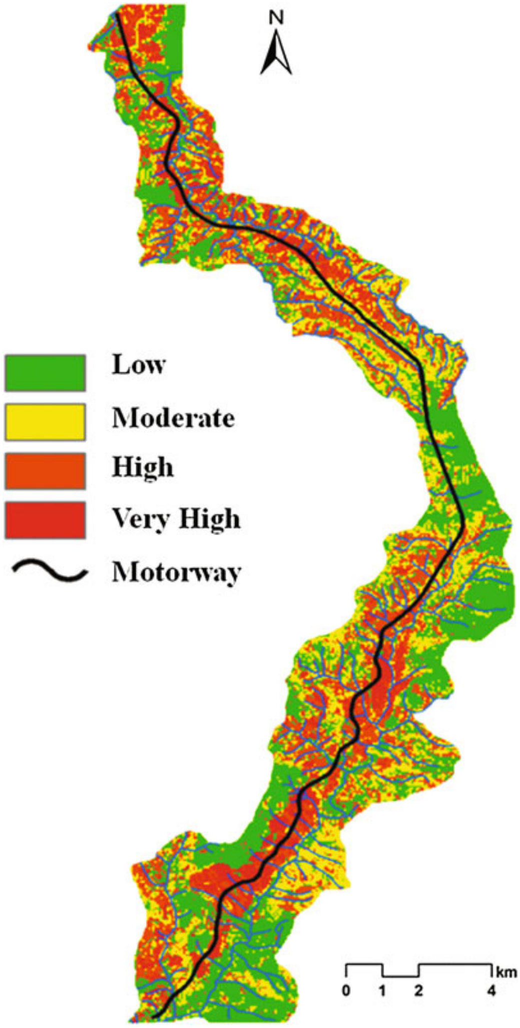


Fig. 3 Landslide susceptibility map of the study area

study areas. The used data layers (Fig. 2) were transformed in raster format.

The land-slide susceptibility was performed on the basis of a 'Conditional Analysis', a statistical method, applied to subdivide territory into Unique Condition Units (Carrara et al. 1995). In this method, landslide susceptibility is expressed as a landslide density in correspondence with

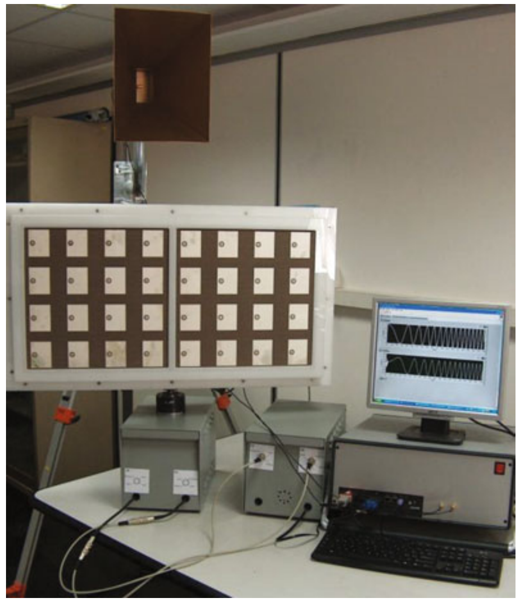


Fig. 4 L-Band radar system

different combinations of predisposing factor classes (Clerici et al. 2006).

The thematic layers were combined in order to obtain all the possible combinations of the various classes of the different predisposing factors. Each specific combination represents a Unique Condition Unit (UCU). Their number and size depend on the criteria used in classifying the predisposing factors. Subsequently, the landslide presence, represented by the landslide area, is determined within each UCU and the landslide density is computed. Assuming that landslides are more likely to occur under those conditions which led to slope-failure in the past, the computed landslide density is equivalent to the future probability of occurrence. The conditional probability is given by:

$$P(L|UCU) = landslide\ area/UCU\ area \quad (1)$$

i.e., the probability of landslide occurrence (L), in an unique combination of factors (UCU), is

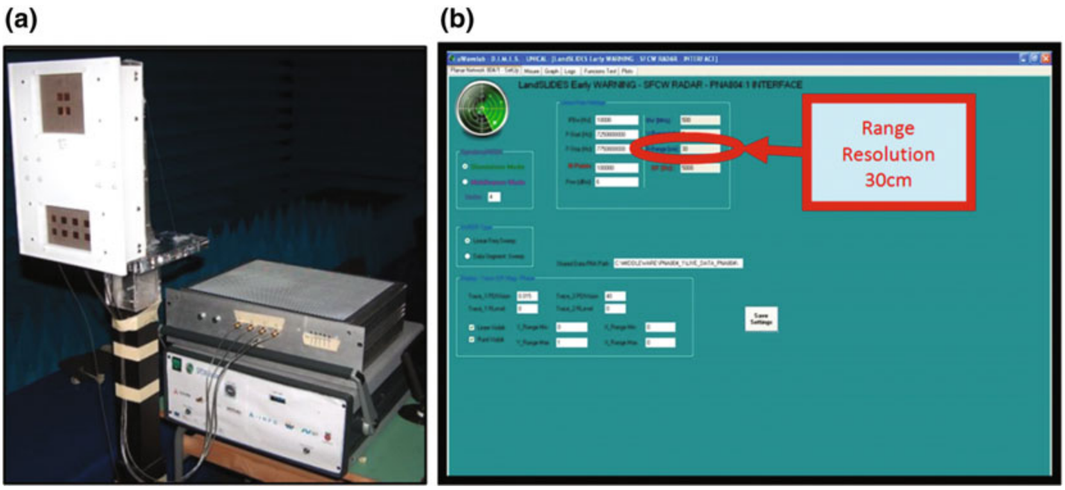
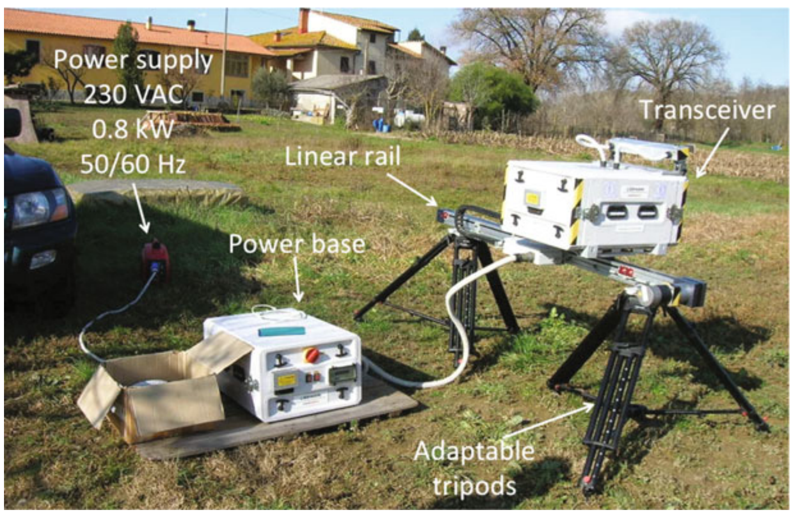


Fig. 5 **a** Radar system and **b** software interface

Fig. 6 Main components of the GB-InSAR system



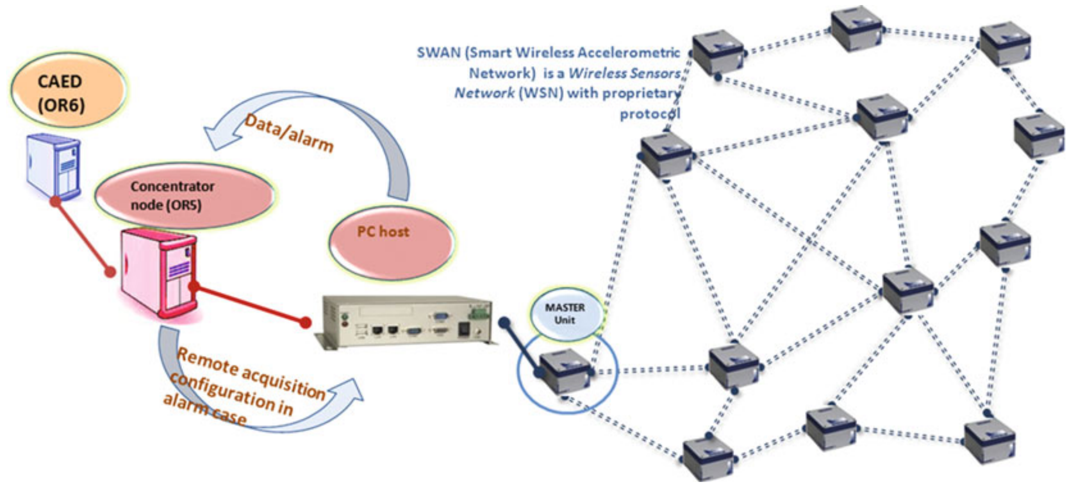


Fig. 7 SWAN system general scheme—communication with CAED via concentrator node

given by the landslide density in that specific UCU. Landslide density in each UCU was computed and the susceptibility map was realized. Of course, this approach only considers the occurred landslides in the inventory database.

As an example, an application of the described methodology is shown in Fig. 3 for a part of motorway "A3, Salerno-Reggio Calabria", between Cosenza Sud and Altilia, northern Calabria (Italy).

3 Displacement Measurement

3.1 Areal Monitoring Systems

The Microwave Lab at University of Calabria developed two compact and low-cost radar configurations (Costanzo et al. 2013), the first one based on the adoption of a software radio platform, the second one using a compact Vector Network Analyzer as a Stepped Frequency Continuous Wave (SFCW) scatterometer module. The Department of Earth Sciences at University of Firenze proposed a portable and versatile Ground-Based Interferometric Synthetic Aperture Radar (GB-InSAR).

The primary goal of the L-band software defined radar is the possibility for the radar signal to go over the possible vegetation layer on the mountain under observation; this justifies the choice of the L-band, able to utilize the wave penetration feature. The radar hardware is depicted in Fig. 4. However, the limit of this radar is the coarse azimuthal resolution, which can be improved by increasing the hardware and software features of the system.

A Stepped-Frequency Continuous-Wave (SFCW) radar has been constructed by adopting a compact Vector Network Analyzer, controlled by a C# .NET interface, and connected through a switch module and a Butler matrix to transmitting and receiving microstrip array antennas, in order to achieve an azimuthal scanning capability able to select a specific investigation area. To capture an entire scene, the scan of four different areas, illuminated by the same microstrip array antenna, is required. Since an operator is not constantly present at the installation site, a framework has been developed for the beam switching in reception and the remote switching on and off of the elements. This allowed us to create a system able to optimize a wide range of goals, such as reduced power consumption, size limits, performance, reliability and cost constraints. A picture of the radar system is illustrated in Fig. 5(a), while the software interface is shown in Fig. 5(b). Concerning the output, from vertical stripes of approximately 90 m, the system provides information on the presence or absence of azimuthal displacements (grouped into size classes of 30 cm), and on the rate of mobilized strip.

The Ground-Based Interferometric Synthetic Aperture RADAR (GB-InSAR, Fig. 6) is able to detect submillimetre displacements for an area up to a few hectares wide. The system is composed of a transceiver, a 2.1 m long linear rail and two antennas moving on it in order to obtain a maximum synthetic aperture of 1.8 m.

The instrument should be placed in front of the selected target at a distance ranging between a few dozen of meters and few kilometers. Spatial resolution is a function of this distance, while precision is a function of employed wavelength (Del Ventisette et al. 2011).

3.2 Point Displacement Measurement Systems

Displacements of terrain and/or other structures at selected points can be monitored, for landslide early warning, including underground troughs and surface point measurement systems. We can obtain significant information by using a wide range of instruments (total stations, Global Navigation Satellite System (GNSS) receivers, opto-mechanical systems, Micro-Electro-Mechanical Systems (MEMS) sensors); underground systems, in particular, imply the drilling of the soil and the installation of inclinometric tubes for every monitored point. The LEWIS project uses both conventional instruments (piezometers, inclinometers, stress cells, time-domain reflectometers (TDRs), meteorological sensors, etc.) and innovative techniques. In the following, the discussion will concern only the latter.

The STRAGO company optimized in the project framework a wireless network, named SWAN (Smart Wireless Accelerometric Network, Fig. 7), consisting of inclinometer units based on MEMS accelerometers (SMAMID unit) for continuous monitoring of landslide survey surface movements, for the purpose of warning/alarm in case of critical events. All system components (hardware, firmware and software) have been improved, increasing computing power and energy savings.

A middleware node concentrator permits data communication from the website (lab/field) to the CAED. The system acquires data with a specified frequency and duration, which are remotely

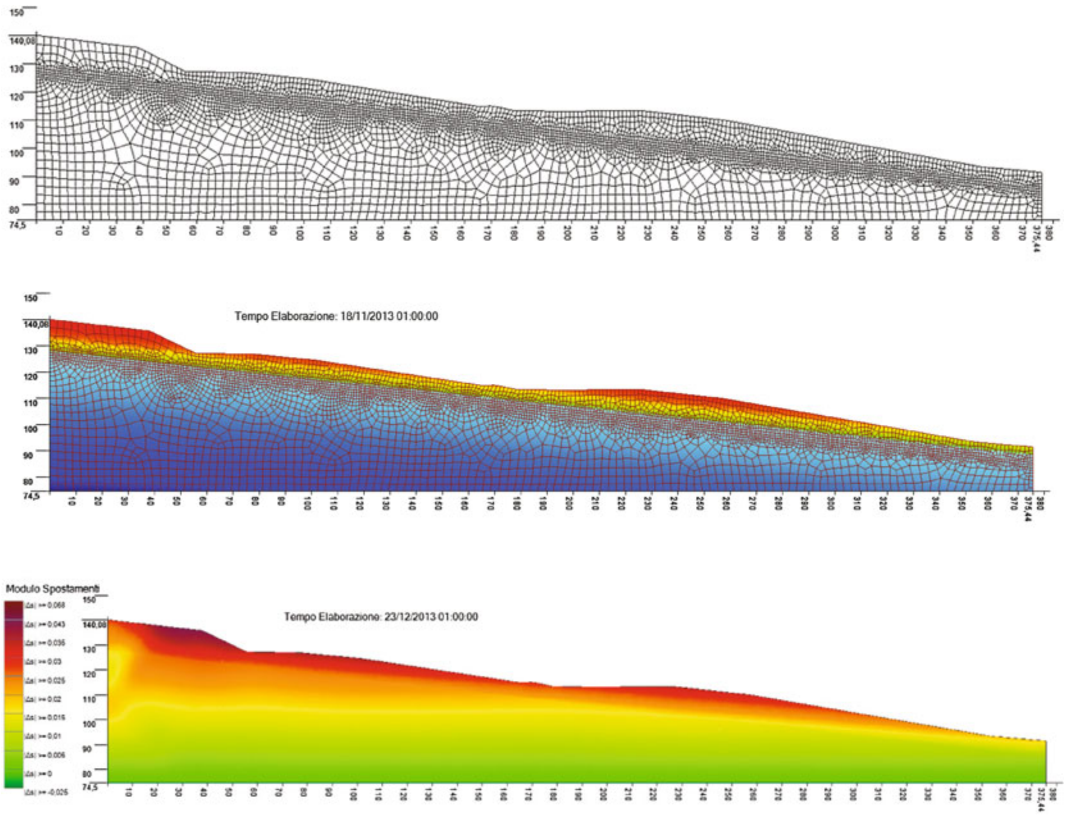


Fig. 8 Example of SUSHI output. Top to bottom, (1) image of the discretization of domain, (2) slope section with color bands indicating pore water pressure distribution, (3) slope section with color bands indicating displacement performed

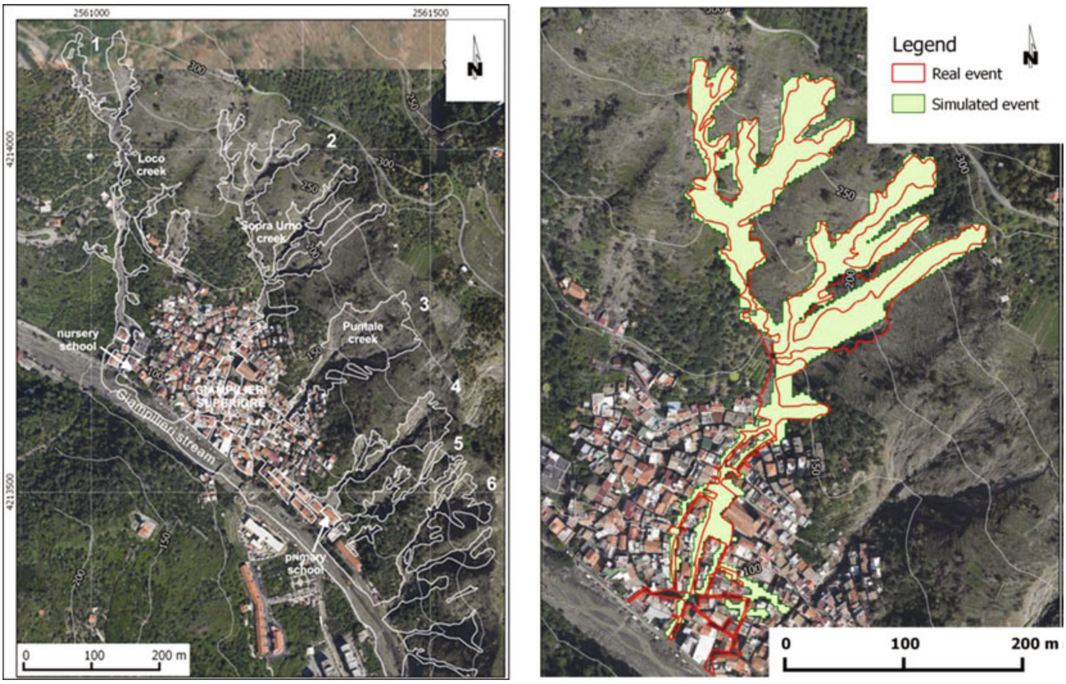


Fig. 9 Left—October 2009 debris flows occurred in Giampilieri Superiore, paths obtained by interpretation of aerial photos. Right—Comparison between Sopra Urno creek debris flows and a simulated event

configurable, and sends a data file containing information concerning each inclinometer measurement point and the landslide status, based on criteria editable by remote control.

The Geomatics Lab of University of Calabria has produced an integrated sensor for position and inclination measurement and monitoring (POsition and Inclination Sensor POIS), characterized by small size (Artese et al. 2015), low weight, low power consumption and low costs.

4 System for Displacement Forecasting

In the context of the modeling and forecasting displacement, a section of the project was devoted to the application of hydro-mechanical models. Three different types of models are used to deal with the analysis on different levels. Models are different for the structure and objectives of analysis.

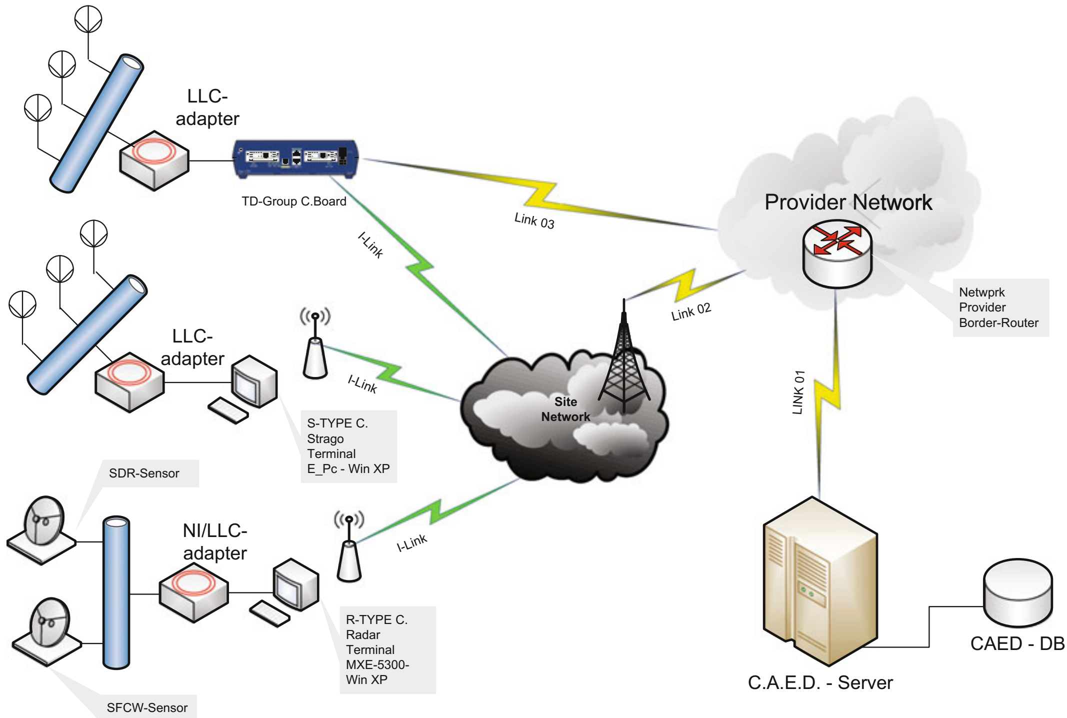


Fig. 10 Network architecture

The first model is named SUSHI (Saturated Unsaturated Simulation for Hillslope Instability), it is applied at slope scale and considers the relation between rainfall infiltration, pore water pressure and slope stability, taking into account several components, including specific site conditions, mechanical, hydraulic and physical soil properties, local seepage conditions, and their contribution to soil strength. Moreover, the model was developed in order to be suitable for cases with strongly heterogeneous soils, irregular domains and variable boundary conditions that vary in space and time. SUSHI is based on the combined use of two modules: an hydraulic module, to analyze the subsoil water circulation due to the rainfall infiltration under transient conditions, and a geotechnical module, which provides indications regarding the slope stability. With regard to the hydraulic module, variably saturated porous media flows were modeled by the classical nonlinear Richards equation:

$$\frac{d\theta(\psi)}{d\psi}\frac{\partial\psi}{\partial t} = C(\psi)\frac{\partial\psi}{\partial t} = \nabla[K(\psi)\nabla\psi] + \frac{\partial K}{\partial z} \tag{2}$$

and closed by constitutive relations describing the functional dependence of moisture content

C and hydraulic conductivity K on the pressure head ψ. Due to the high nonlinearity in the constitutive relations, analytical solutions of Richards equations rarely exist except for a limited number of simple configurations. For this reason, the Galerkin-type finite element method was used. In the geotechnical module the equations to be solved are the following:

$$\frac{\partial \sigma'_{ij}}{\partial x_j} + \frac{\partial u_w}{\partial x_i} + \gamma \delta_{iz} = 0 \qquad (3)$$

where σ'_{ij} are the stress components, u_w is the pore pressure calculated from the hydraulic module, γ is the soil unit weight and δ_{iz} is the Kronecker symbol. The linear constitutive equations (plane stress) and strain-displacement relationship also must be taken into account. The displacement formulation is considered in the present approach in which stress and strain are eliminated, resulting in differential equations in which the displacements are the variables. Then, discretization and application of Galerkin's method leads to the stiffness equations for a typical element. To solve the equation over a generic domain an assembly strategy is chosen, leading to global algebraic linear equations $[K_G]\{U\} = \{F\}$ where $\{U\}$ and $\{F\}$ are the nodal variables (displacements) and known force components (gravity loading and seepage loads) respectively. The model takes into account material non linearity using constant stiffness iterations, in which non linearity is introduced by iteratively modifying the loads vector $\{F\}$: the loads vector at each iteration consists of externally applied loads and self-equilibrating loads that have the effect of redistributing stresses within the domain. The Mohr-Coulomb criterion was chosen to represent the yield function and associated flow was assumed. Also the self-equilibrating loads were calculated using an initial strain method. By means of the presented geotechnical module it is possible to assess:

- the safety factor of the slope subjected to gravity loading and to the pore pressure calculated from the hydraulic module;
- displacement, strain and stress under the effect of rainfall infiltration.

Another model is of areal type, named Geotop (Rigon et al. 2006), that couples a hydrological and a geotechnical module for the computation of the shallow landslide safety factor under the assumption of an infinite slope hypothesis. The hydrological module concerns a three-dimensional (3-D), physically based, spatially distributed model that performs water and energy budgets at pixel scale. It performs subsurface saturated and unsaturated flows, surface runoff, channel flows, and turbulent fluxes across the soil-atmosphere interface (e.g., latent and sensible heat fluxes, soil temperature, etc.). Tools for parameter calibration are used in order to estimate parameters of the soil water retention curve by comparing simulated suction and soil water content with those coming from the in situ sensors along test site of the project. The results are moisture, soil suction, and water table depth maps at different soil depths of the digital watershed model where it is applied. The geotechnical module uses these outputs and parameters such as soil friction angle and cohesion, root cohesion and local slope, in order to provide infinite slope safety factor raster maps for each soil layer for all the computational domain. The system's components are integrated by using the modelling framework Object Modeling System 3.0, which includes many model facilities such as tools for model output visualization, algorithms for model parameters calibration and sensitivity analysis.

Finally, a third model deals with the analysis of the debris flow propagation. It follows the innovative guidelines of the Cellular Automata (CA) methodology to develop efficient models for simulating complex dynamic systems, that evolve mainly on the base of local interactions of their constituent parts. Debris flows may be considered such a type of complex systems. Modeling such dangerous phenomena can supply new tools, using computer simulations to evaluate debris flow hazards and the effects of possible remedial works in the considered areas. In our application we use the Giampilieri zone (southern Italy, Peres and Cancelliere 2014), which was devastated in October 1st, 2009 by several catastrophic debris flows, triggered by high intensity rainfall concentrated in a few hours. In this context, SCIDDICA-SS3 (Simulation through Computational Innovative methods for the Detection of Debris flow path using Interactive Cellular Automata—both Subaerial and Subaqueous ones, Avolio et al. 2013) was used, which is a new version model of the SCIDDICA-SS family, that improves approximations regarding momentum conservation (Fig. 8).

The Giampilieri village is located on the eastern slopes of the Peloritani Mountains on the

Table 1 Thickness classification (THI)

Class	Type	Description (m)
THI1	Very shallow	≤ 0.5
THI2	Shallow	≤ 2
THI3	Medium	≤ 10
THI4	Deep	≤ 30
THI5	Very deep	>30

Table 2 Magnitude classification (MAG)

Class	Type
MAG1	Low
MAG2	Moderate
MAG3	High

Table 3 Geometric Index classification (GEI)

Class	Type	Description
GEI1	Very Small	All SUR, SCA, VOL, THI are equal to 1
GEI2	Small	At least a value is equal to 2 among SUR, SCA, VOL, THI
GEI3	Moderate	At least a value is equal to 3 among SUR, SCA, VOL, THI
GEI4	Large	At least a value is equal to 4 among SUR, SCA, VOL, THI
GEI5	Very Large	At least a value is equal to 5 among SUR, SCA, VOL, THI

Table 4 Velocity classification (VEL)

Class	Type	Description
VEL1	Slow	Slides, flows, spreads (<1 m/year)
VEL2	Moderate	Earth and debris flows, complex landslides (1 m/year to 1 m/h)
VEL3	Rapid	Falls and topples, rock slides and debris flows (>1 m/h)

Table 5 Matrix for magnitude estimation (MAG)

	VEL1	VEL2	VEL3
GEI1	MAG1	MAG1	MAG1
GEI2	MAG1	MAG1	MAG2
GEI3	MAG1	MAG2	MAG3
GEI4	MAG2	MAG3	MAG3
GEI5	MAG3	MAG3	MAG3

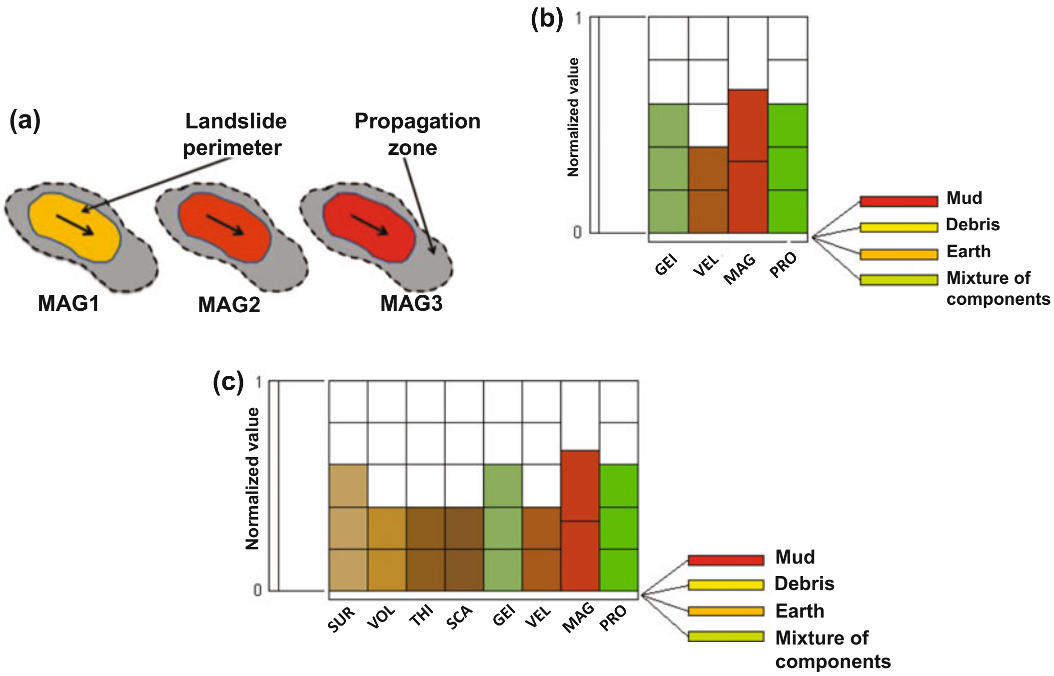


Fig. 11 Map of event scenarios: **a** level 1; **b** level 2; **c** level 3

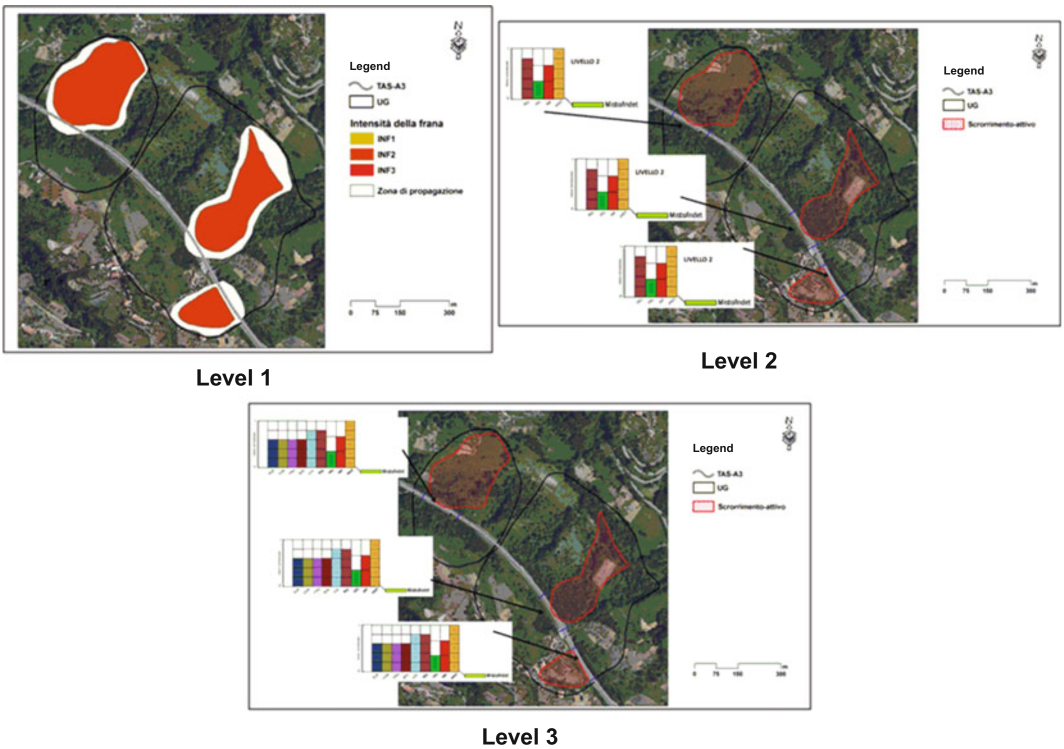


Fig. 12 Map of event scenarios: application for A3 motorway—Mancarelli and Fiego

left side of Giampilieri River. It is settled on ancient alluvial fan and is crossed by various creeks, tributaries of the Giampilieri River. During this 2009 alluvial event, several debris flows were mobilized from the basins behind the town (Fig. 9), and reached Giampilieri Superiore. The mutual interaction between different, nearly simultaneous, debris flows produced dramatic effects in terms of loss of human lives and damages to buildings close to the hill and along the principal streams that cross the town. Crossing the centre, the flows killed 19 people, destroyed houses and dragged away whatever was in their path.

Simulations were performed for the six debris flows that occurred in the Giampilieri area in 2009 (indicated with numbers from 1 to 6 in Fig. 9). In particular, the no. 2 debris flow was used in the model calibration phase (Fig. 9) while the other ones were used for model validation. The results show a good capability of the model to simulate the debris run-out, particularly in the upslope parts of the basins, while in the downslope urbanized area, the reproduction of the real events is less accurate, with significant differences due to lateral spreading. The model behaviour was satisfactory in terms of reproducing the global dynamic of the events, such as velocity, debris flow depth, thickness of deposit, and, in particular, the path of debris flows, that show a good correspondence with the real events. The program could be refined for the reproduction of debris flow propagation into highly urbanized areas, where streets are narrow. This improvement may be obtained by a better

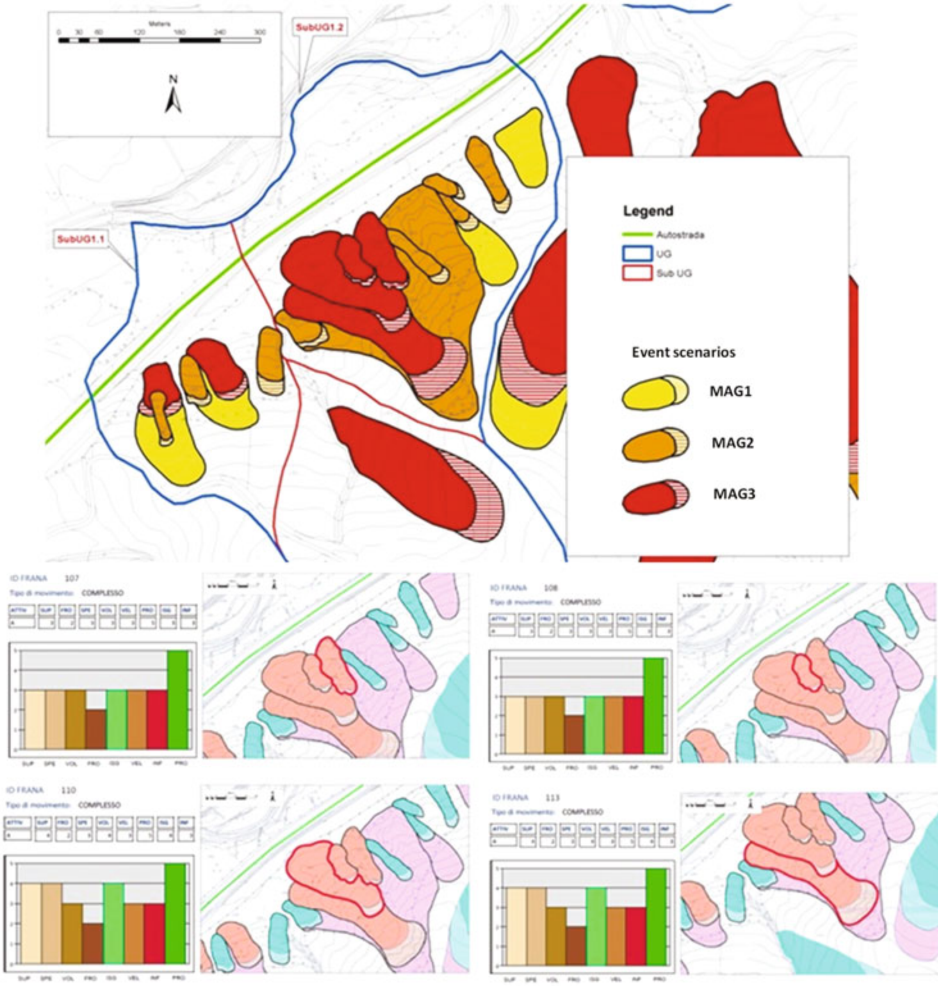


Fig. 13 Map of event scenarios: application for A16 motorway—km112+400

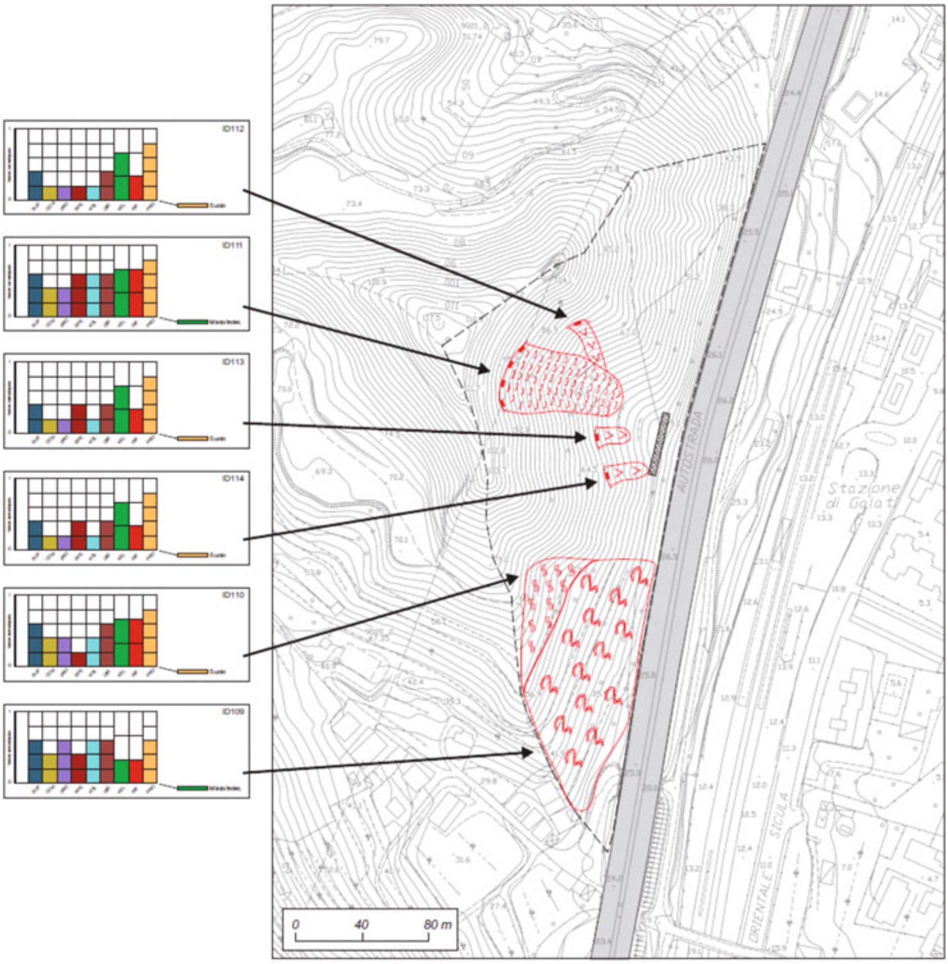


Fig. 14 Map of event scenarios: application for A18 motorway

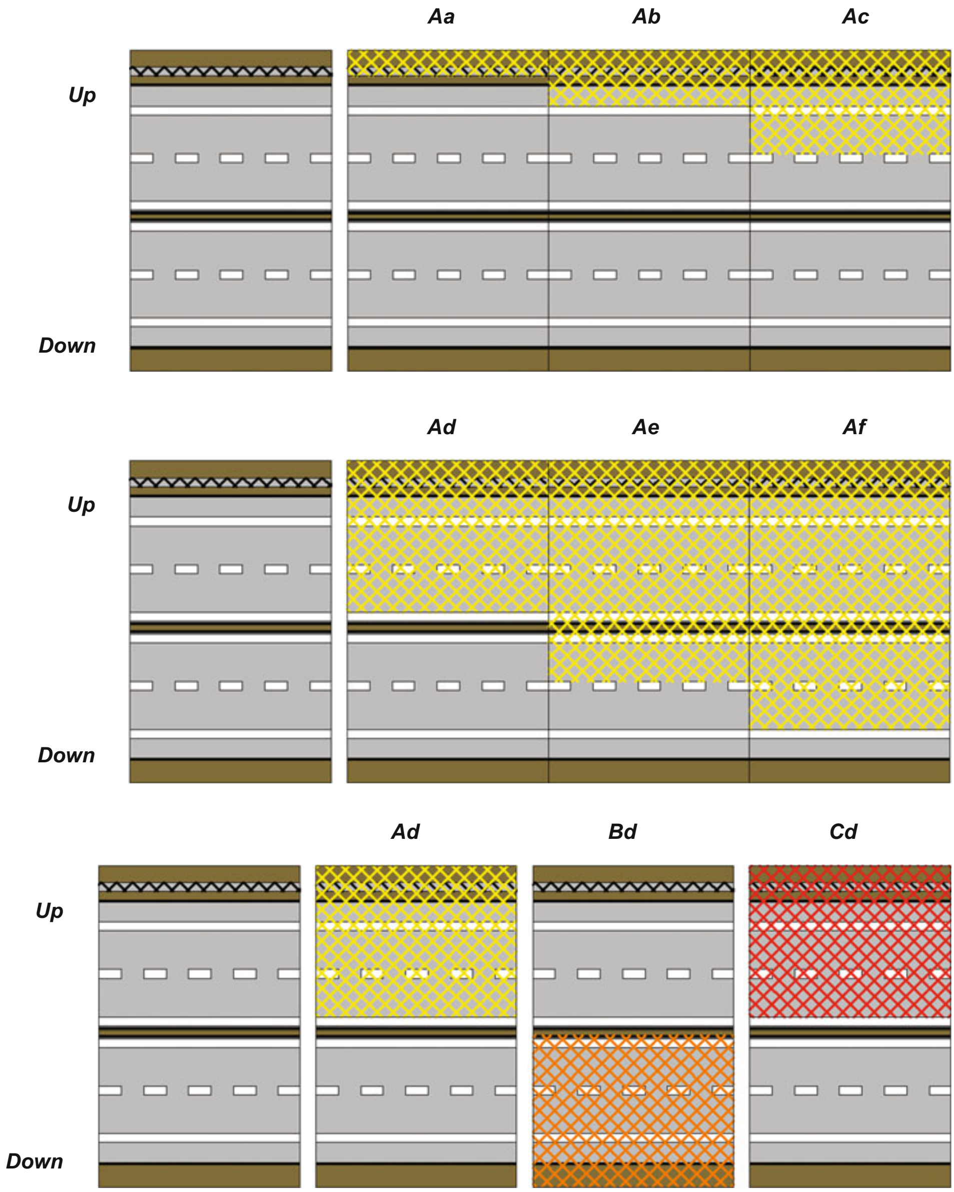


Fig. 15 Risk scenarios (class A: *dotted yellow lines*; class B: *dotted orange lines*; class C: *dotted red lines*)

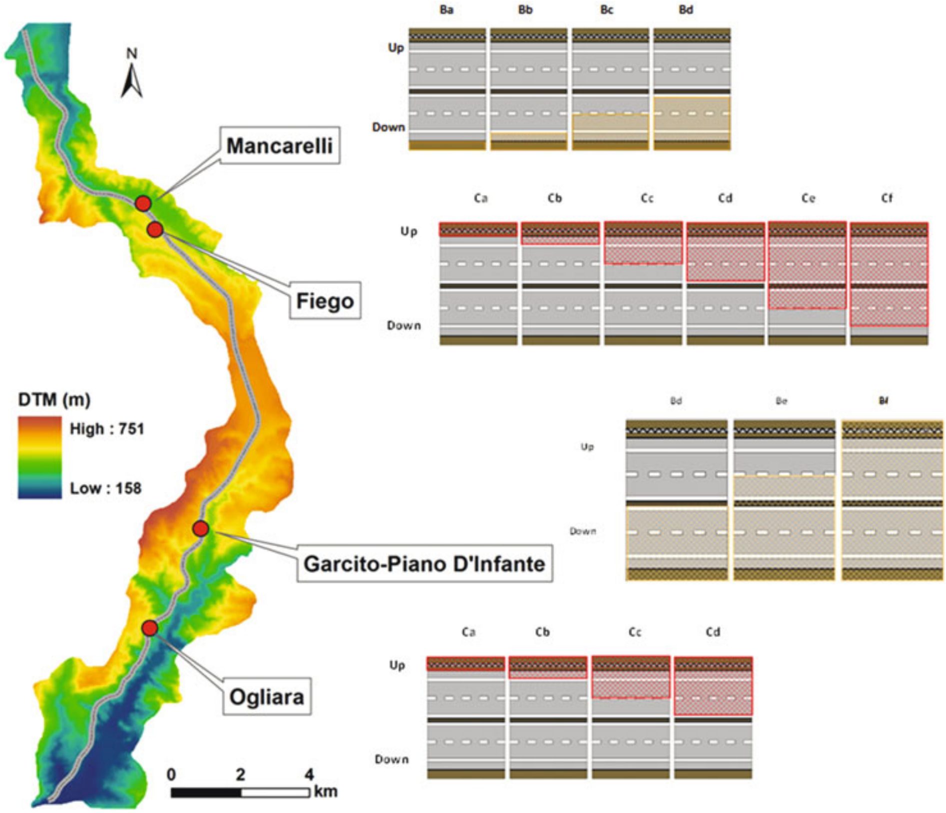


Fig. 16 Risk scenarios—application for A3 motorway

Table 6 CAED possible decisions

State of sensors and/or models	CAED decisions
All INDs and SENs are S0	0—no decision
At least one IND is S1 and all SENs are S0	1—activation of SOD (Sensors On Demand)
At least one SEN is S1	2—to intensify the presence up to 24 h/day
At least *n* SENs are S1 or at least one SEN is S2	3/1—to issue a notice of ordinary criticality (level 1)
At least *n* SENs are S2 or at least one SEN is S3	3/2—to issue a notice of moderate criticality (level 2)
At least *n* SENs are S3	3/3—to issue a notice of high or severe criticality (level 3)

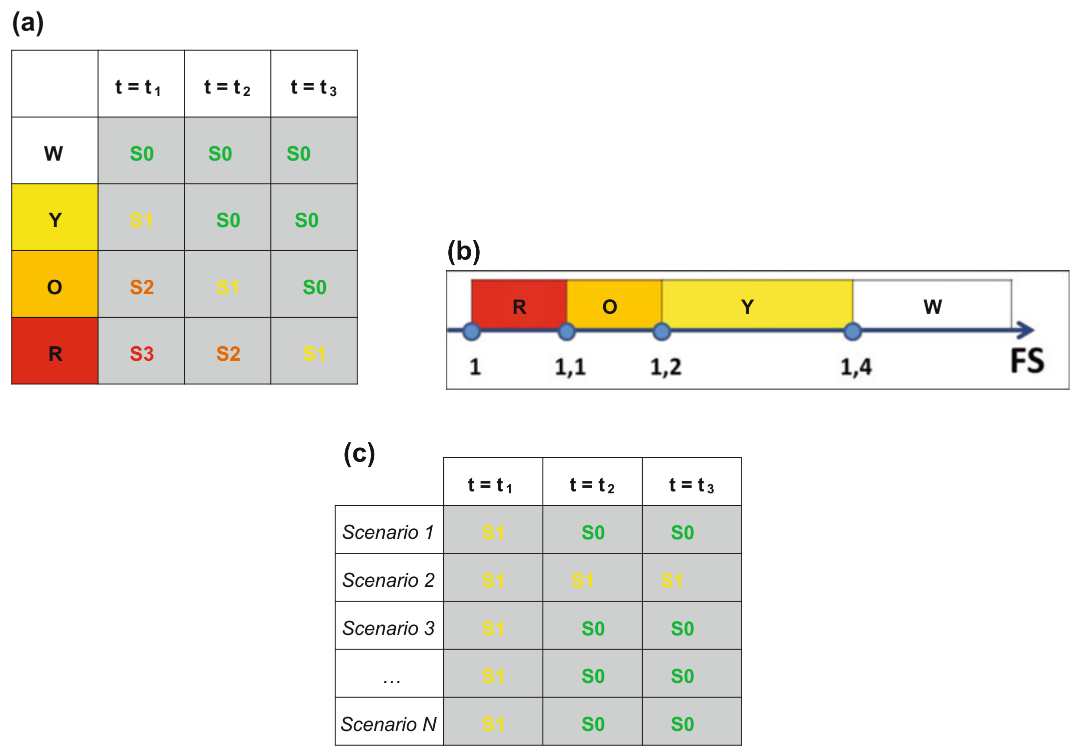


Fig. 17 **a** Matrix for definition of sensor state; **b** values of factor of safety; **c** state of sensor, related to several predicted scenarios

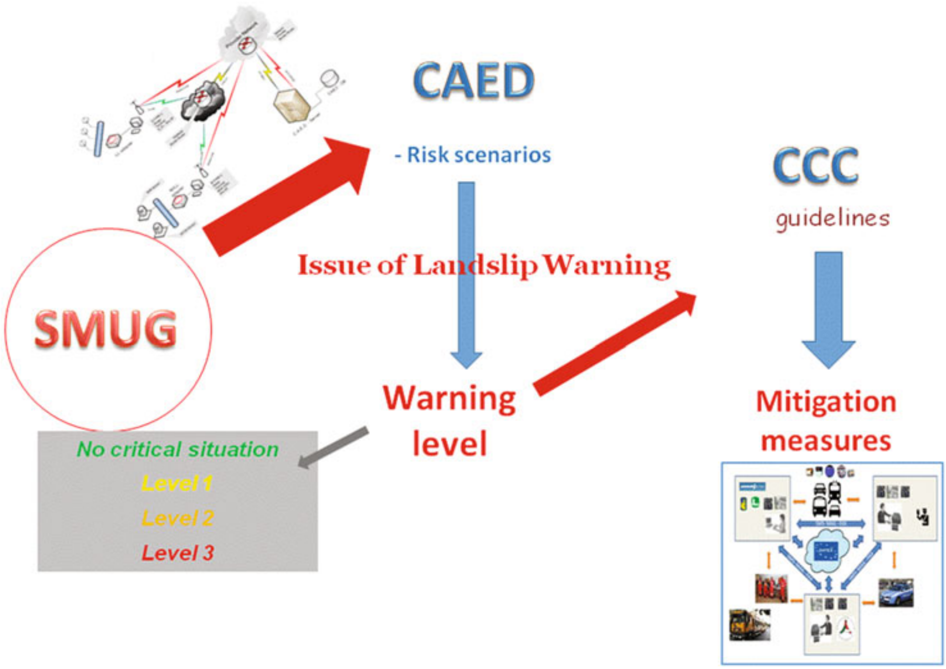


Fig. 18 Relationship among LEWIS components

cell discretization of the computation region, which enables accurate positioning of buildings.

5 Data Transmission Network

A network architecture with hybrid configuration, named LEWARNET ('Landscape Early WARning NETwork', Fig. 10) is used for data transmission from the various sensors involved in the monitoring (e.g., SDRadar, SFCW scatterometer, interferometer, SMAMID sensors) towards the CAED. The chosen topology can be represented by a three-level network, with a connection between the CAED and the monitoring sites through a direct link or by sink nodes.

The network framework includes: (1) a server component working as a software interface, designed in agreement with CAED specifications; (2) an own middleware, including all software components for the management of the sink nodes, namely the monitoring of the client process, the definition of data structures for the storage and the management of data messages, encryption utility and data compression utility; (3) the client software components for each sensor belonging to a sink node, namely the specific software interfaces established in agreement with the sensors designers.

The main task of the middleware implements the following functionalities: (i) 'Warm Up', consisting in the actions relative to the identification of CAED server and active sensors (network and sensor discovery); (ii) 'Messages Queue Manager', devoting to the management of messages queues in input/output from the sensors and towards the CAED; (iii) 'Activities Logger', devoting to the generation of log files reporting all developed activities and activated processes.

6 Data Collecting and Processing Center (CAED)

Management of information flows, telematic architecture and services for data management is entrusted to the Data Collecting and Processing Centre (CAED, namely "Centro Acquisizione ed Elaborazione Dati").

The CAED ensures the continuous exchange of information among monitoring networks, mathematical models and the Command and Control Centre (CCC) that is responsible for emergency management. A communication protocol, implemented by the CAED and named AqSERV, allows for the management of data flow from the monitoring network. AqSERV was designed by considering the heterogeneity of devices of monitoring and transmission networks (point and areal sensors) and the available hardware resources (microcontrollers and/or industrial computers). AqSERV was designed to link the CAED database (named LewisDB) and the monitoring networks, after validation for the authenticity of the node that connects to the centre. Data acquisition, before the storage in the database, is validated both syntactically and according to the information content. The procedures for extraction of the information content and validation were realized differently for point and areal sensors: the latter require a more complex validation, as they work in a 2D domain. The complete management of the monitoring networks by CAED is ensured by specific remote commands, sent to individual devices via AqSERV, to reconfigure the acquisition intervals or to activate any sensor, depending on the natural phenomena occurring in real time. The acquired and validated data are then accessible for the mathematical models through a further service, created ad hoc, which publishes all the acquisitions by sensors on a remote server for sharing. The configuration of the monitoring networks (composed of devices and sensors), the communication protocol used by each network, and the rules for extraction and validation of information content are carried out through a web application, that allows the users to manage the whole system.

7 Control Centre for Road Networks

The Centre, which is devoted to Road Infrastructure Monitoring and Management (CCC, namely "Centro di Comando e Controllo"), manages a monitoring and supervising system. It is responsible for integrating data from hydrogeological risk monitoring and traffic and road condition information, considering relevant alerts, and initiating road maintenance and traffic management operations based on global situation evaluation, which will act based on specifically designed management rules and procedures, derived from the emergency plan.

The CCC is able to activate communication channels with the operating and rescue teams in an automated way, after operator validation of the danger situations recognized by the systems. In addition, it may easily interact with other operating centers responsible for road management and safety (such as Authorities, Road Police, Civil Defence, Viability Patrols, etc.). Automatic Communication has been implemented by machine-generated messages, both on traditional communication means (such as e-mail, telefax, SMS, speech) and by a specific innovation in this framework, by means of DATEX protocol (www.datex2.eu), and up-to-date technology and machine readable protocol.

The functions performed by the CCC: Check the environmental conditions; Monitor traffic status; Detect eventual abnormal conditions and situations; Find out the intervention/information procedures to be applied against certain situations; Trigger the intervention/information procedures (whether directly or actively involved in the operation); Check the progress of the interventions; Check the information delivered on different media.

The organizational and procedural model provides a broad vision of the problem showing several operations centres (police, rescue organizations, road operators) that are able to interact with other operational centres through traditional and up-to-date technology communication means. CCC can operate by acting as a road operational centre that directly activates emergency rescue teams and patrols, and as well may implement the actions required to manage the critical situation. Otherwise, it can operate as a supervisory central, which gets information from other operating centres to oversee, and coordinate several collaborating operating centres, monitoring and triggering management risk and initiating specific rescue and management operations.

8 The Intervention Model

An intervention model is based on the following elements: Event scenarios, Risk scenarios, Levels of criticality, Levels of alert.

Event scenarios describe the properties of expected phenomena in terms of dimension, velocity, involved material and probability of occurrence. Occurrence probability depends on the associated time frame, which should be equal to a few hours at most for Early Warning Systems. Evaluation of occurrence probability is carried out by using information from monitoring systems and/or from outputs of adopted mathematical models for nowcasting. All the properties, to be analyzed for event scenarios, are listed below. A subdivision in classes is adopted for each one:

- Landslide velocity (3 classes from slow to rapid)—**VEL**;
- Landslide surface (5 classes from very small to very large)—**SUR**;
- Landslide scarp (5 classes from very small to very large)—**SCA**;
- Landslide volume (5 classes from extremely small to large)—**VOL**;
- Thickness (5 classes from very shallow to very deep)—**THI**;
- Magnitude (3 classes: low, moderate, high), which combines the previous information—**MAG**;
- Involved material (mud, debris, earth, rock, mixture of components)—**IM**;
- Occurrence probability (zero, low, moderate, high, very high, equal to 1)—**PRO**.

As an example, thickness classification is reported in Table 1.

The landslide magnitude is estimated by considering velocity and a Geometric Index (GEI), below defined, and three classes are identified (Table 2).

In details, GEI synthetizes the landslide dimensions and it is a combination of four parameters (SUR, SCA, VOL, THI); five classes are defined, as reported in Table 3.

Regarding landslide velocity (VEL), the classification of Cruden and Varnes (1996) was considered. In particular, three classes are detailed (Table 4).

Finally, landslide magnitude is computed by using the matrix given in Table 5.

Representation of event scenarios can be carried out by using in synthetic way the hazard or intensity of a phenomenon. In this work, three levels of representation (Fig. 11) are proposed: the first one is only related to intensity and, due to its simplicity, it allows to immediately identify which are the most dangerous phenomena. The other two levels also provide an indication of occurrence probability, and therefore the hazard of the phenomenon.

Some examples of application are reported in Figs. 12, 13 and 14.

Risk scenarios can be firstly grouped in the following three classes:

A. Mud and/or debris movements which could induce a friction reduction and facilitate slips (indicated with dotted yellow lines in Figs. 15 and 16);
B. Road subsidence induced by landslides that could drag or drop vehicles (indicated with dotted orange lines in Figs. 15 and 16);
C. Falls of significant volumes and/or boulders that could crush or cover vehicles and constitute an obstacle for others vehicles (indicated with dotted red lines in Figs. 15 and 16).

For each previous risk scenario, six sub-scenarios can be identified on the basis of the number of potentially involved infrastructure elements, carriageways and lanes: (a) hydraulic infrastructures and/or barriers, (b) only emergency lanes, (c) lanes, (d) fast lanes, (e) fast lanes of the opposite carriageway, (f) lanes of the opposite carriageway).

Thus, there are 18 possible risk scenarios, indicated by a couple of letters (Capital and small, Fig. 15). An application for A3 motorway is shown in Fig. 16.

For identifying the ***levels of criticality***, the CAED acquires measurements from sensors and model outputs. Moreover, CAED identifies four states for each of them: state 0 = no variation; state 1 = small variation; state 2 = moderate variation; state 3 = high variation. These four states were set with heuristic criteria and only the acquisition of experimental data will allow for a better definition of them.

Besides information from sensors and models, meteorological and hydrological models (named as indicators) give other information.

Indicators comprise weather forecasting and output of FLaIR model (Forecasting of Landslide induced by rainfall, Capparelli and Versace 2011) based on observed and predicted (for the successive six hours) rainfall heights.

Indicators define two states:

- state 0 = no variation or not significant;
- state 1 = significant variation.

To sum up, CAED has the following information in any moment:

- state (0, 1) of indicators (IND);
- state (0, 1, 2, 3) of sensors and models running for the specific highway segment (SEN);

and, on the basis of these states, four different decisions can be made by CAED, one of which with three options, that activate different level of criticality.

All the possible decisions are illustrated in Table 6, in which the weight of the several sensors is assumed to be the same.

As an example, identification of a state related to the SUSHI model is below described. SUSHI output is constituted by a series of Factor of Safety (FS) values, estimated on the basis on rainfall heights, which are measured and predicted with a stochastic model. In particular, the stochastic model provide N hyetographs for input in SUSHI, and the final result is a matrix of FS values, which are computed for several time instants (t_0, t_1, t_2, …) and different rainfall inputs.

Based on FS, the state S is defined by using the matrix reported in Fig. 17a, that considers:

(i) four levels of FS (see also Fig. 17b), indicated as W (white), Y (yellow), O (orange) and R (red); (ii) the instant of prediction.

A greater weight is assigned to estimation very close to current instant t_0, as it is less uncertain.

Moreover:

- for each t, N values of S are provided (Fig. 17c), corresponding to N rainfall realizations;
- the highest value of S, which occurred in at least 10% of realizations, is assigned to each t;
- N is usually set equal to 100, and 3 time instants are fixed, for which $t_1–t_0 = t_2–t_1 = t_3–t_2 = 1$ h.

Thus, SUSHI model provides 3 values of S, related to t_1, t_2 and t_3, respectively.

Based on the notices of criticality levels provided by CAED, and on its own independent evaluations, the CCC issues the appropriate **level of alert** (Surveillance, Alert, Alarm and Warning) and makes decisions about the consequent actions (Fig. 18).

9 Conclusions

The example here proposed only provides a framework of a specific case of early warning system that was designed and realized for research and testing purposes. Obviously, given the huge variability of natural contexts, it cannot represent all the cases that might occur in reality. Depending on the specific site, it is necessary to evaluate and complete the best configuration.

Many problems still remain open, such as the definition of the threshold levels, the intervention model, the use of monitoring instruments or devices to spread alarms.

For such complex and so hyper-calibrated systems it is necessary to ensure an adequate validation period for better understanding the dynamics and for better defining all the implemented procedures.

References

Artese G, Perrelli M, Artese S. Meduri S, Brogno N (2015) POIS, a low cost tilt and position sensor: design and first tests, vol 5(5). Multidisciplinary Digital Publishing Institute

Avolio MV, Di Gregorio S, Lupiano V, Mazzanti P (2013) SCIDDICA-SS3: a new version of cellular automata model for simulating fast moving landslides. J Supercomput. doi:10.1007/s11227-013-0948-1

Capparelli G, Versace P (2011) FLaIR and SUSHI: two mathematical models for early warning systems for rainfall induced landslides. Landslides 8:67–79. doi:10.1007/s10346-010-0228-6

Carrara A, Cardinali M, Guzzetti F, Reichenbach P (1995) GIS technology in mapping landslide hazard. In: Carrara A, Guzzetti F (eds) Geographical information systems in assessing natural hazards. Kluwer Academic Publisher, Dordrecht, pp 135–175

Clerici A, Perego S, Tellini C, Vescovi P (2006) A GIS-based automated procedure for landslide susceptibility mapping by the conditional analysis method: the Baganza valley case study (Italian Northern Apennines). Env Geol 50:941–961

Costanzo S, Spadafora MOH, Scarcella F, DiMassa G (2013) Multiband software defined radar for soil discontinuities detection, J Electr Comput Eng. Article ID 379832

Cruden DM, Varnes DJ (1996) Landslide types and processes. Nat Acad Sci 247:36–75 (Special Report, Transportation Research Board)

Del Ventisette C, Intrieri E, Luzi G, Casagli N, Fanti R, Leva D (2011) Using ground based radar interferometry during emergency: the case of the A3 motorway (Calabria Region, Italy) threatened by a landslide. Nat Hazards Earth Syst Sci 11(9):2483–2495. doi:10.5194/nhess-11-2483-2011

Intrieri E, Gigli G, Casagli N, Nadim F (2013) Landslide Early Warning System: toolbox and general concepts. Nat Hazards Earth Syst Sci 13(85–90):2013. doi:10.5194/nhess-13-85-2013

Peres DJ, Cancelliere A (2014) Accounting for variability in rain-event intensity and initial conditions in landslide triggering return period mapping via a monte carlo approach. In: Landslide Science for a safer geoenvironment: volume 2: methods of landslide studies, pp 499–505

Rigon R, Bertoldi G, Over TM (2006) GEOtop: a distributed hydrological model with coupled water and energy budgets. J Hydromet 7:371–388

Sassa K, Yueping Y (2010) Early warning of landslides. Geological Publishing House, 166 p

VanWestern CJ, Castellanos Abella EA, Sekhar LK (2008) Spatial data for landslide susceptibility, hazards and vulnerability assessment: an overview. Eng Geol 102:112–131

Versace P, Artese G, Autiero M, Avolio MV, Bardi F, Borgia A, Cancelliere A, Capparelli G, Capuozzo M, Caruso A, Casagli N, Cavallaro L, Cianciosi O, Conforti M, Conte E, Costanzo A, Costanzo S, De Marinis M, Di Gregorio S, Di Massa G, De Luca DL, De Santis D, Donato A, Fanti R, Fidolini F, Formetta G, Foti E, Intrieri E, La Sala G, Luci A, Maletta D, Mannara G, Moreno D, Morrone L, Mungari T, Muto F, Paoletti F, Peres DJ, Raffo A, Rago V, Rigon R, Spadafora F, Spataro W, Troncone A, Trunfio GA, Vena M, Viggiani G (2014) An Integrated System for Landslide Monitoring, Early Warning and Risk Mitigation along Lifelines. In: Capparelli G, Greco R (eds) Aspetti idrologici e Idraulici per il controllo dei movimenti franosi, pp 1–68