Web Processing Services for Shallow Landslide

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Abstract
This work evaluates the capability of Web Processing Service (WPS) to foster the shallow landslides hazard awareness. In particular this study demonstrates how the WPS can provide an ideal environment for the development of real-time applications by creating a process chain able to couple two widely used models, TRIGRS and DFWALK, respectively applied for (i) the localization and characterization of areas susceptible to shallow landslides and (ii) the assessment of these landslides run-out in case of collapse. The service has been built with the PyWPS software by integrating the models through the GIS GRASS. The application, tested for the case study of Ha Giang (Vietnam), can be generally deployed and used both as service for shallow landslide hazard forecast and as a tool for the identification of vulnerable areas for emergency planning design.

1. Introduction

Global climate change is going to increase the risk exposure of millions of people all over the world, but major disasters have to be expected in developing countries where poorest people are located in vulnerable areas and have little or none information on impending hazards. In particular, in Southeast Asia, according to Yusuf and Francisco (2009), the climate change in the next years will contribute in exacerbate the impact of natural calamities like droughts, floods, landslides and cyclones, mostly in the following "hotspot" countries: Philippines, Vietnam, Cambodia, Thailand, Laos, Sumatra and Indonesia. Actually these changes are already happening: according to the report "Viet Nam Climate Change, Adaptation and Poor People" (Oxfam, 2008), in the last years rainfall, while remaining largely stable in term of mean annual volume, recorded important regional variation due to localized increased intensity and unpredictability of events. As a consequence the changes in precipitation patterns have increased the occurrence of rainfall induced landslides and their produced damages. This is particularly true in tropical mountainous regions, like those present in North Vietnam, where heavy rains brought by monsoon seasons, hurricanes and typhoons are combined with steep terrains. This general trend has been confirmed by the study conducted on the worldwide records of fatality-inducing landslides of the 2007 by Petley (2008). It shows that 24.0% of landslide events and 20.0% of landslide fatalities occurred in Southeast Asia. In total the whole Asia was responsible for 82.5% of fatal landslide events and for 75.9% of the fatalities. Petley also highlighted that the fatality rate per landslide in Asia is very high if compared with Europe (11.1 versus 1.6) and that Vietnam is one of the six most vulnerable countries to rainfall triggered landslides. As a result of the above mentioned studies, it is clear that Vietnam is highly exposed to rainfall induced landslides and that in the future years this vulnerability, according to global climate change scenarios, is expected to increase. Moreover the high rate of fatalities suggests that insufficient mitigation measures are available and therefore further researches and applications are required. One of the contributions that the geospatial science can provide to support the reduction of this type of risks is the development of accessible applications able to communicate in a simple and widely understandable way the current situation and the expected hazards. Taking into account these considerations this work aims to develop a Web service application that by using existing open standard is able to generate hazard maps as a result of processes simulations and data analyses.

2. System Design

To reduce the risk due to natural hazards like shallow landslides, mathematical models can play an important role because they allow the objective assessment of where a landslide may occur and what area may be involved: these are valuable information that can be integrated into landuse management, urban planning and population protection plans in order to support decision-making

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in taking efficient countermeasures and prompt disaster responses. As regards the shallow landslide modeling, the authors have identified two models successfully applied in many cases: TRIGRS (Transient Rainfall Grid-Based Regional Slope Stability; Baum et al., 2008) and DFWALK (Debris Flow Walk; Gamma, 1999), respectively used to (i) predict the possible localization and activated volume of instabilities and (ii) to simulate the landslide run-out. Unfortunately these two complementary software are not linked together, and thus do not permit their direct usage in predicting when, where and with what intensity a phenomenon can occur. With the present research the authors intend to investigate the possibility to couple the TRIGRS and DFWALK using an OGC open standard named Web Processing Service that offers geo-processing capabilities across the web. Such a kind of system should follow the process chain illustrated in Figure 1 where the user calls a WPS service that initially runs the TRIGRS model for assessment of landslide activation zones and the related potential displaced volume: at this stage the TRIGRS output data should become the input data for DFWALK model that evaluates the landslide expansion area. At the end of this second process the result returned to the user is a shallow landslide intensity map of the processed area: this map estimates the severity level of the event and is described in Loat and Petrascheck (1997). In the following sections, the three main components of the application (WPS, TRIGRS and DFWALK) are described.

2.1 Web Processing Service

Web Processing Service is an open standard developed and promoted by the Open Geospatial Consortium to provide "*client access across a network to pre-programmed calculations and/or computation model that operate on spatially referred data*" (Open Geospatial Consortium, 2007). This standard virtually offers any sort of calculation through the Internet by defining a standard communication between a service provider and its potential client: it establishes how the client has to submit a processing task to a server and how the outputs from the process are delivered.

In this regard, Web Processing Service supports three type of requests: *GetCapabilities*, *DescribeProcess* and *Execute*. The *GetCapabilities* request provides to the clients basic metadata about the service (description, version, keywords, fees, access constraints), the service provider (name, site, contact) and the supported language and operations; it also returns a list of the processes offered by the service by specifying for each of them an identifier and a brief description of its objective. The *DescribeProcess* request is used to have detailed information about a process of interest; in particular this request returns a list of the required and/or optional inputs and outputs of a process with their characteristics. Among others minimum and maximum occurrence, default value (if exists), unit of measure, type (complex data, literal data or bounding box data) and format (mimetype, encoding and schema) are specified for each parameter. The *Execute* request allows the user to run the process of interest by providing the input data according to the rules specified into the *DescribeProcess* response. The above mentioned requests can be sent to the server either by using HTTP GET or HTTP POST methods: the former allows the client to submit KVP (key-value pairs) encoded requests as part of a URL while in the latter the request is encoded into a XML form. The service responses are always provided in XML documents compliant with the standard.

2.2 Phenomena Modeling: TRIGRS and DFWALK Models

TRIGRS is a model capable to evaluate the effect over time of a storm on the slope stability by considering the local geotechnical characteristics and the water infiltration processes. It has the ability to model on a spatial distribute domain (raster) the transient water infiltration, by means of the Richards equation as proposed by Iverson (2000), and the runoff process according to a user-defined flow-routing mechanism like the "D-inf" proposed by Tarboton (1997). As in most of these types of models, the slope stability is evaluated by means of the infinite-slope analysis (Taylor, 1954 and Lambe and Whitman, 1979).

Figure 1: Application system workflow

For further details on the model equations the interested readers are invited to read the USGS open file report by Baum et al., (2008). TRIGRS requires a large number of specific parameters, most of which can be provided either as constant value or raster map (ESRI GRID ASCII files). They are, grouped by scope:

- Hydro-geological data (elevation, slope, basal boundary depth, water table initial depth, steady pre-storm infiltration rate, hydraulic diffusivity, soil cohesion, friction angle, etc.);
- Storm properties (a storm is divided into *n* discrete periods, each one defined by a value of rainfall intensity and cumulative duration);
- Data for runoff-routing calculations (flow-direction grid, topographic index list, weighting factor list for downslope receptor cells, etc.); this data are optional and they can be obtained by running *TopoIndex*, a utility tool provided within the TRIGRS code;
- Program control parameters (number of cells, rows and columns of the grid data, number of vertical increments, etc.).

All the above settings are to be defined in an initialization file where also the outputs paths of the following grids generated by TRIGRS must be provided:

- Runoff and actual infiltration rates for each storm period;
- Factor of safety and pressure head at the maximum depth of calculation;
- Minimum factor of safety;
- Depth and pressure head corresponding to the minimum factor of safety.

The program offers also the possibility to obtain a detailed text file with a list of pressure head and factor of safety values calculated at each depth increment. DFWALK is an empirical-conceptual model able to reproduce the mass expansion and deposition of landslides. This approach originally proposed by Gamma (1999) and further developed by the Institute of Earth sciences in Lugano, combines different approaches: the physical description of motion by means of the Perla frictional model (Perla et al., 1980), the stochastic estimation of expansion by mean of a Monte Carlo random walk simulation, and the empirical assessment of deposition through a weighted slope-velocity function. For further information on the model equations see Cannata and Molinari (2008). DFWALK mandatory requires as input raster maps the DTM (Digital Terrain Model) and the grid of the landslide activation cells; to better define the landslide propagation there is also the possibility to optionally provide additional raster maps: one with the potential obstacles (for example buildings) and the other with the preferential pathways (for example streets). Moreover, the model requires some numeric input parameters that refer to the different approaches implemented in the model: sliding friction coefficient and mass-to-drag ratio to calculate the landslide velocity with the Perla model; expansion coefficient and number of random walk to estimate the landslide run-out; slope, velocity and maximum sedimentation thresholds to simulate the accumulation process. Given the volume detached for each source cell the model simulates the landslide run-out and provides information about random walk paths, velocities and sedimentation heights.

3. Process Chain and Implementation Steps

Figure 2 shows the process architecture that has been developed in Ubuntu 9.10 operating system: the application can be represented as a chain of GRASS GIS (GRASS Development Team, 2011 and Neteler et al., 2012) modules called by the PyWPS (PyWPS Development Team, 2009; Cepicky and Becchi, 2007) Web Processing Service. In the following paragraph each step of the process with relative development is presented.

Step 1: TRIGRS Model

The first process of the chain is the assessment of the effects of a storm on the slope stability by using the TRIGRS model (version 2.0). TRIGRS is written in Fortran programming language and is freely available from the USGS (U.S. Geological Survey) website (http://pubs.usgs.gov/of/2008/-1159/). While for Windows or Macintosh users the executables are directly available, Linux users have to compile the source code: operation that requires some minor changes in the original code to be successfully carried out against the *gfort* compiler. To limit the inputs requirements, the model has to be calibrated for the application area and for this reason all the parameters, listed in paragraph 2.2, with the exception of the storm properties (rainfall intensities and durations) shall be fixed. For the scope of the system, among the various outputs that the model can provide, the only two TRIGRS outputs raster maps to be considered are the values of the minimum factor of safety (*fs_map*) and the corresponding depth at which they are calculated (*z_map*). TRIGRS has a loosely-coupled level of integration with a Geographical Information System (GIS), which means that inputs and outputs have to be manually imported/exported to/from GIS.

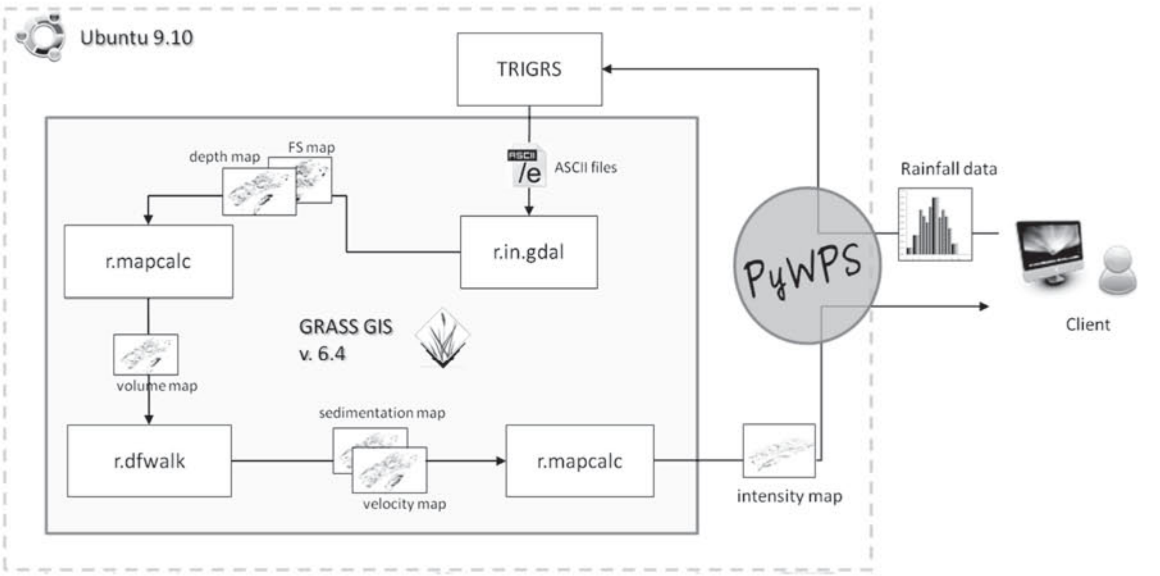

Figure 2: Implemented process architecture

Thus to integrate the model in the process chain we automated the conversion of user input data, according to TRIGRS requirements, and imported the model output maps in the GRASS GIS environment through *r.in.gdal* GRASS module.

Step 2: Calculation of the Unstable Volume Map
This step is performed using a GRASS GIS specific module, *r.mapcalc*, which allows arithmetic and logical calculations on raster map layers by using the following map algebra (Shapiro and Westervelt, 1994) condition:

vol_map = if (*fs_map*<1.0, *z_map* *Xres*Yres, 0.0)

Equation 1

where the map of the unstable volumes (*vol_map*) is calculated as the product of the unstable cells depth (*z_map*) and their corresponding area. The latter is calculated using the raster resolutions in *x* (*Xres*) and *y* dimensions (*Yres*). This calculation is performed only where TRIGRS detected an instability (*fs_map*<1), otherwise the assigned value to the cells is zero.

Step 3: Execution of the DFWALK Model
The map of unstable volumes (*vol_map*) is the only input required by the process to run the DFWALK model: in fact, similarly to the TRIGRS case, all the other required parameters were fixed after a model calibration. DFWALK is a GIS embedded model: it has already been ported to GRASS GIS by the Institute of Earth sciences as *r.dfwalk* native module (available on GRASS-Addons-SVN repository). Originally, the module required to specify a single unstable area by dividing the activated volume between each starting cell. During the process implementation, the C code of the module has been modified to allow for using of multiple non-contiguous unstable areas. This step outputs are the velocity and accumulation maps (*vel_map*, *acc_map*) to be used in the next step 4 for evaluating the shallow landslide intensity map.

Step 4: Intensity Classification
This last step is achieved by using the module *r.mapcalc* which derives an intensity map classified in three levels of severity. This is performed by applying defined thresholds that, as suggested by Egli (1999) in the case of shallow landslide events, are set on the key parameters flow velocity and sedimentation height.

int_map = if(acc_map!=0.0 && vel_map!=0.0,
if(acc_map>1.0 && vel_map>1.0, 3.0, 2.0),null())

Equation 2

The intensity map resulting by the map algebra of expression 2, is therefore a reclassification that assigns:

(i) High level of intensity (value 3) to areas with flow rates and sedimentation heights greater than, respectively, 1 m/s and 1 m.
(ii) Medium level of intensity (value 2) to the other cases (flow rates less than or equal to1 m/s or sedimentation heights less than or equal to 1 m).

Note that according to Egli (1999) the lowest level of intensity is not considered for this type of phenomenon and that in this application a high level of intensity is also assigned to the activation areas detected by TRIGRS model.

4. Case Study: Ha Giang Area

The area selected for testing this implementation is the Vi Xuyen district-Ha Giang city (Figure 3), located in the Ha Giang province in the North of Vietnam. The topography of the area is dominated by the upland area of Tongba Mountain whose summit height is about 685 m above sea level; there is a secondary summit just to the East at 625 m. The land steeply drops on all sides, towards the Lo River on the East and North sides, and to the interior river valley on the West side of the mountain. A streams network drains the mountain area; most of the rainfall run-off and of the landslide material have generally been channeled into these streams causing considerable damages to property, roads and bridges. The geology of the Ha Giang area consists of metamorphic rocks over 400 million years old and is described in Dovjikov et al., (1965). The faults in the area are low-angle reverse faults or thrusts, which have emplaced younger rocks onto older rocks. Faults are orientated at a large angle, more than 40 - 45 degrees, to the northerly and easterly facing slopes that have failed, and dip towards the south and south west. As such they are at close to right angles with the failed slope and thus far less likely to fail than a fracture at a low angle or sub-parallel to the slope surface. The role of the bedrock geology in the landslide event is critical but indirect. The presence of the high ground and slope profile is controlled by the underlying geology, the folding and faulting of which has resulted in the current relief. The different hardness of adjoining formations, such as hard metamorphosed sandstones and more easily weathered schists, has resulted in the stepped profile of the hillside. A north-south fault line, which may contain material which is easier to erode than the surrounding rocks, forms part of the course of the stream flowing (Lo River). Another important factor is that these rock types are all highly impermeable, being tightly cemented and compact, thus have a high run off rate during rainfall compared to more permeable rocks such as younger limestone or sandstone.

4.1 Ha Giang Landslides

The underlying geology can be ruled out as the primary causal factor in triggering the landslides. While geological faults occur in the area the underlying bedrock is tectonically stable. Also there are no drift deposits in which lines of weakness could have developed. It is believed that exceptionally heavy rainfall event combined with the condition of the peat bog and the very steep slope location are triggering factors of the shallow landslide that often occurred in this area. During the very hot and dry summer the peat dries out considerably, it contracts in volume, and develops cracks in the peat surface and probably within the mass of the peat. This unusual physical structure of the peat meant that the rainfall could penetrate quickly to the base of the peat and generate a type of sheet flow, which would cause the development of a slip surface at the interface with the bedrock. The nature of this slip surface, as described above, suggests that this set of conditions happened very quickly creating a downslope force of considerable momentum to dislodge so much debris. Ha Giang Mountain region is a hot-spot for shallow landslides, in fact, in the past, they occurred on almost all the slopes and as reported by VietNam Society website (http://vietnamsociety.dztimes.net), during the first seven months of 2010, in the area 17 people were killed or went missing and 42 houses were destroyed due to floods and rainfall-induced landslides. In Table 1 some information about the events that occurred in the last years are listed.

Table 1: Landslides occurred in Ha Giang (VN2000/UTM48N coordinates)

Name	Location (X - Y)	Area [m²]	Damage
QS01	446,946.030 – 2,521,729.692	104,436	causing traffic congestion
QS02	446,727.764 – 2,525,055.076	140,147	causing traffic congestion
QS03	443,580.530 - 2,525,490.648	46,781	causing traffic congestion
QS04	441,995.347 – 2,522,469.487	64,969	causing traffic congestion
QS05	447,569.704 – 2,527,572.602	86,933	causing traffic congestion
QS06	447,759.547 – 2,514,673.835	56,174	causing traffic congestion
QS07	448,368.697 – 2,521,282.946	61,404	buried land
QS08	448,340.298 – 2,523,532.308	28,844	causing traffic congestion
QS09	448,067.011 – 2,524,572.363	13,688	causing traffic congestion
QS10	446,659.809 – 2,527,114.988	30,459	causing traffic congestion

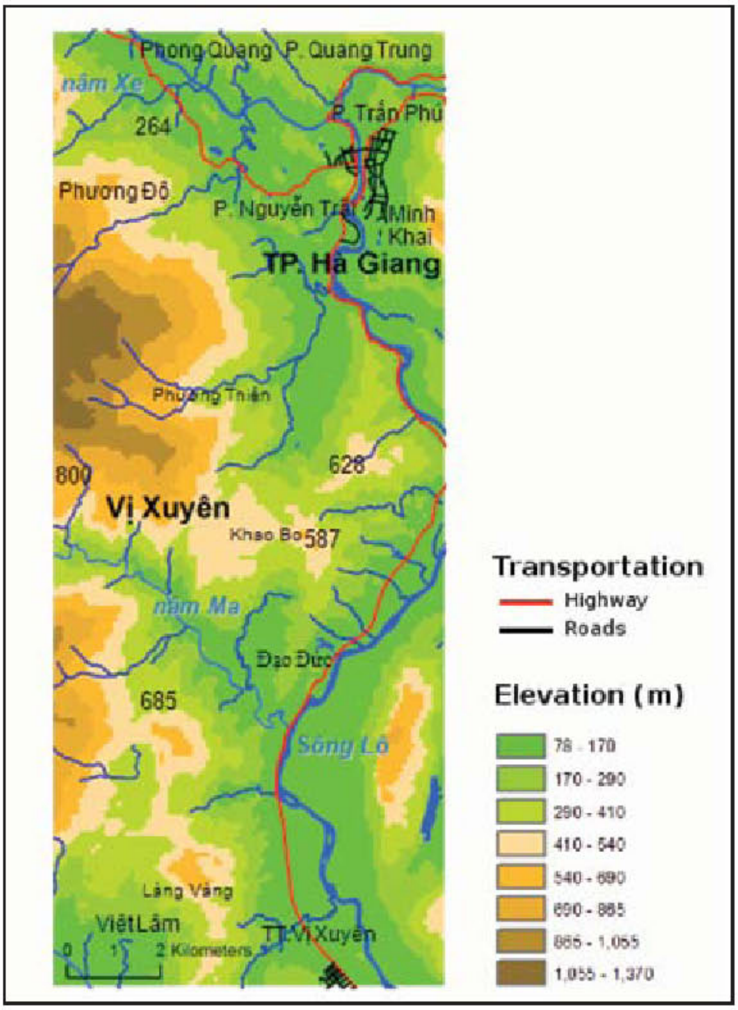

Figure 3: Study Area: Vi Xuyen district-Ha Giang city

Table 2: Extension of the processing area (VN2000/UTM48N coordinates)

Processing region	
North [m]	2,528,268
South [m]	2,507,748
East [m]	448,738
West [m]	440,278
Resolution [m]	90
Cells number	21,432
Area [km^2]	173.6

4.2WPS Process Deployment

To test the WPS process implemented on Ha Giang area, a first phase of the work was intended to prepare all the input data of the project. A specific GRASS GIS location has been created to manage and store all the input raster maps required for the running of the TRIGRS and DFWALK models. The location defines also the extension of the test area whose coordinates and resolution are specified in Table 2. All the necessary information to set up the process has been derived by the analysis of three basic maps: the SRTM 90 m Digital Elevation Model (version 4), available on the CGIAR Consortium for Spatial Information website (http://srtm.csi.cgiar.org/), the topographic coverage at 1:10,000 and the bedrock geology map at 1:50,000. In particular, the last map has been used to sub-divide the study region into three main classes with similar hydro-geological characteristics.

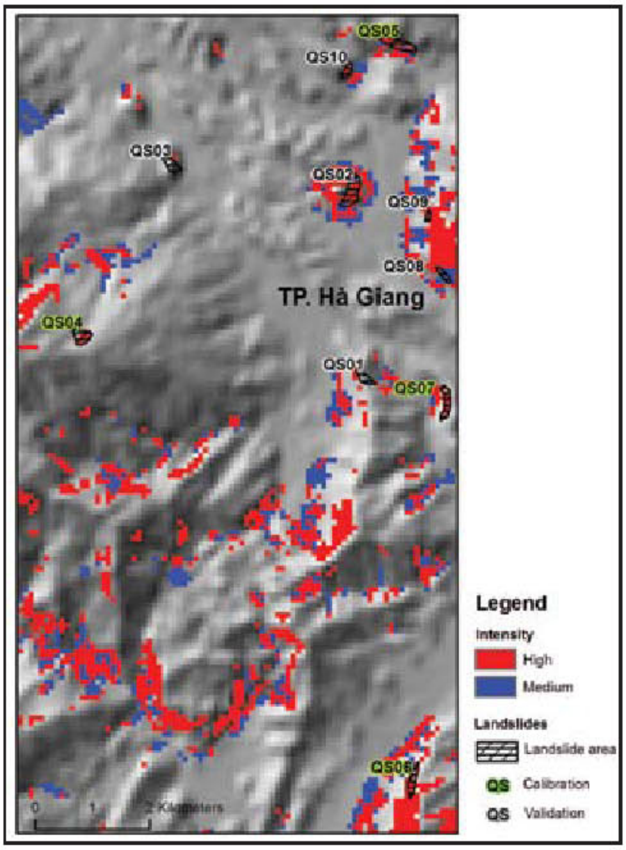

Figure 4: Validation process: first results

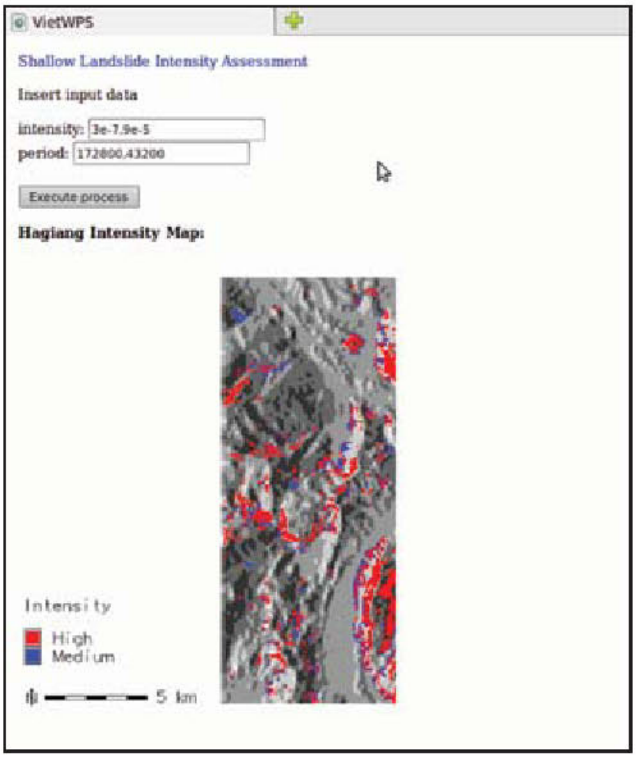

Figure 5: WPS process tested on Ha Giang area

The calibration of the models has been performed by a "trial and error" approach driven by some past events records (landslides QS04, QS05, QS06 and QS07 listed in Table 1) and the knowledge of the local geological/geotechnical soil characteristics; this procedure led to defining the parameters reported in Table 3 and Table 4 and used in the process set-up. Figure 4 reports the results of a first validation analysis based on six landslide observations, the ones grey-highlighted: QS01, QS02, QS03, QS08, QS09, QS10. The others four landslides (green-highlighted) are the observations used for the calibration process. The map shows that the processing intensity areas successfully detected most of the observed events; some improvements are still needed to obtain a complete matching of modeled and observed data, both in term of additional data integration and calibration process refinement. Regarding the WPS process, as specified in the paragraph 2.1, it is accessible through a simple HTTP requests (GET or POST method).

A DescribeProcess request allows to retrieve information about the process: in this case the input parameters are a list of rainfall intensities values (in meters per second) and a list of rainfall lenghts (in seconds), both comma separated, while the output is the URL to the intensity map image. An Execute request allows running the process and retrieving the results. In order to simplify and provide a more user-friendly application, a simple rough interface has been developed taking advantage of the AJAX (Asynchronous JavaScript and XML) techniques that allow performing a WPS *Execute* request by taking the inputs from an HTML form. The process response in XML format is automatically retrieved and parsed by the interface that loads the output intensity map image. Figure 5 shows a screenshot of the interface with WPS process successfully tested on Ha Giang area. In terms of performance, the whole process, that involves 21,432 cells and is run on a virtual machine with 500 Mb of RAM and Intel dual core processor, takes an average of about 2 minutes.

Table 3: TRIGRS: key hydro-geological parameters after calibration

Parameter Description	**Zone 1**	**Zone 2**	**Zone 3**
Soil cohesion [N/m^2]	2,600	2,800	3,200
Angle of internal friction [deg]	36	39	38
Total unit weight of soil [kN/m^3]	27	26.5	26
Hydraulic diffusivity [m^2/s]	8.0e-04	7.0e-04	5.0e-04
Vertical hydraulic conductivity on saturated soil [m/s]	4.0e-06	5.0e-06	7.0e-06
Soil saturated volumetric water content	0.70	0.65	0.55
Soil residual volumetric water content	0.06	0.06	0.06

Table 4: DFWALK: model parameters after calibration

Parameter Description	**Value**
Slope limit threshold for sedimentation [%]	36
Expansion coefficient [-]	1.80
Mean slope of conoid [%]	10
Perla mass-to-drag rough coefficient [m]	70
Perla slippering rough coefficient [-]	0.10
Maximum speed at which there is deposition [m/s]	8
Maximum slope at which there is deposition [%]	20
Maximum deposition possible due to slope or speed in a single cell for a random walk [m]	0.20
Maximum volume deposition possible per random walk [m^3]	1,000

5. Conclusion and Future Works

Nowadays the world around the hazard and risk management is quickly changing along with the enhancements of the fundamental technology which it is based on. Geomatic in particular is playing an important role in the integrated management by supplying key information to stakeholders in a geospatial contest. The role of decision makers is to collect and analyze information derived by a series of sources that have to be fused in order to create the desired integrated view that allows taking decisions based on a comprehensive view of the situation. With this regards, open standards play a fundamental role in enhancing the capability of data fusion and therefore effectively help in correctly manage the hazard and the available resources for its mitigation. With this research the authors have proven the maturity and capacity of the Web Processing Service to be an effective technology for dynamic intensity assessment. During this study, a web processing service for the intensity assessment of rainfall induced shallow landslides has been implemented. The service allows to chain a series of processes that are finalized to coupling the TRIGRS and DFWALK models, respectively used for landslides activation zones identification and for landslides run-out assessment, and to assess the hazard derived by a given rainfall event. This procedure has been realized by using OGC WPS, the Open Geospatial Consortium open standard for the geoprocessing sharing over the Internet. A simple interface has been also implemented to ease the data entry and the outputs visualization. This application, developed and tested in an area of the Ha Giang province, has demonstrated how dynamic intensity assessment can be provided to risk management. Managers could use this process, (*i*) to predict where and with what intensity shallow landslides could occur if opportunely integrated with weather forecasts, or (*ii*) to identify high vulnerable zones and design emergency plans if weather statistics are used. For the continuation of this research, the authors are undertaking further studies on the capability of this process to operate at a local scale by using high resolution data. In future applications the authors would like to perform a better calibration process based on the automatic calibration tool UCODE (Hill, 1998) and additional data.

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