GeoPatterns, Vol. II, Issue 1, April 2017, pp. 6-12

A summary of CRMD new research on landslides using multi-temporal InSAR techniques based on Sentinel-1 data

Iuliana Armaș
Faculty of Geography, University of Bucharest
iulia_armas@geo.unibuc.com

Abstract. The new landslide research direction at CRMD aims to improve and develop new applications of ground-based validation techniques of satellite radar interferometry displacement products, based on Sentinel-1 data. The test area is the high slope instability ridge of the Carpathian and Subcarpathian Prahova Valley due to natural and anthropogenic factors. We use sets of single polarized synthetic aperture radar (SAR) satellite data acquired by historical (*i.e.*, ERS-1/-2 and ENVISAT) and recent (Sentinel-1) satellites, and multi-temporal radar interferometry (InSAR) methodologies to provide maps of line-of-sight displacements. We apply some of the most advanced differential interferometric Synthetic Aperture Radar techniques at the moment, Persistent Scatterer Interferometry (PSI) and Small BASeline Subset (SBAS); both of them are applied for depicting areal or point deformations. Deformation maps and time series are integrated with Geographical Information System (GIS) multilayer analysis results derived from classical methodologies (*i.e.*, geological and geomorphological methods), and field research. InSAR analyzes are calibrated and validated using GNSS techniques and GIS slope modelling based on Lidar and radar obtained DEMs. The short-term results are highly reliable interferometric measurements. On a long term, the results imply the understanding of slope dynamic in the context of major human environmental change. The latter achievement could offer the support to successful risk mitigation methodologies in mountain areas.

Keywords: *Landslides, InSAR, Permanent Scatterers, SBAS, GNSS*

1. INTRODUCTION

Landslides are among the most widespread geomorphological processes in the hilly regions of Romania built of Neogene molasse deposits, as well as in the mountainous regions developed on Cretaceous and Paleogene flysch (Balteanu *et al.* 2012), were slope instabilities raise frequent problems to authorities and stakeholders. Slope instability is estimated as a concordance/non-concordance association between specific local evolution patterns, reflected in a specific slope geometry. The principle behind this thinking is the fact that the dynamic of any geomorphological system is imprinted in its shape. If the shape is concordant with the sustained dynamic pattern then the geomorphological system is stable and has a reduced vulnerability. If the non-concordance between shape and internal dynamics increases, the system moves towards changing its shape. The resistance to change leads to build-up pressure growing the potential of sharp discharges of energy, manifested in this case as slope dynamics.

Landscapes with high relief energy represent areas of high potential instability, as slope-type surfaces are the dominant geomorphological features. More than 60% of Romania territory is represented by orogeny, and is highly sensitive to climate changes.

The danger of potential unstable slopes to human habitats, especially in hilly and mountain areas – as slopes are dominant – is also of primary importance in practice and research after 1990, due to an explosive increase in value of the damage caused especially by landslide disasters (UN/ISDR, 2004; CRED, 2015). Observing potentially unstable slopes is also of primary importance in accordance with sustainable development requests, as pointed out by the European Commission in several documents (*e.g.* EC 2009-2014), in the context of predicted environmental changes (*e.g. IPCC 2012, EEA 2005, EEA 2007, EEA 2012* – http://www.eea.europa.eu*)*.

Slope instability research has long term theoretical and practical results, offering the support to successful risk mitigation actions in mountain areas at European and international level (*e.g.*, Lee *et al.*, 2002, Sarkar *et al.*, 2004, Thaiyuenwong and Maireang, 2010; Muntohar and Liao, 2010). The Earth observation from space component is essential in understanding slope dynamics. Successful applications have applied ground-based and remote sensing techniques and products; the on-going trend being the multi-technique landslide observations for multi-scale analysis (*e.g.*, Noland *et al.*, 2003, Metternicht *et al.*, 2005). More recently, multi-temporal InSAR techniques represent an important tool for measuring landslide displacement that offers a repeated insight over the area of interest at various scales (Necsoiu *et al.*, 2014).

In Romania, landslide investigations have a long tradition, but more in a descriptive way and focused on the geomorphological mapping. Susceptibility and hazard maps, based on expert judgment and heuristic methods associated with the use of GIS techniques, or even statistical methods, have been elaborated after the year 2000 (*e.g.*, Armas 2011, Armas *et al.*, 2014, Bălteanu and Micu 2009, Micu *et al.*, 2010, Micu *et al.*, 2014) but the analysis of slope instability in Romania hasn't been based on satellite interferometric products so far.

The launch of Sentinel-1 brings new opportunities in unstable slopes and landslides monitoring applications. Sentinel-1 is a two-satellite constellation for Land and Ocean monitoring, consisting of Sentinel-1A and Sentinel-1B satellites. Launched by ESA on 3rd of April 2014 and 25th of April 2016 respectively, the two satellites provide C-Band SAR data continuity at a spatial resolution of 20 m x 5 m, after the retirement of ERS and Envisat missions. The C-band sensor offers high temporal resolution data, made freely available by ESA. The constellation of two satellites orbit the earth 180° apart, providing data every 6 days.

Due to the novelty of the data, the studies that have been done so far are exploratory, assessing the potential of using Sentinel data in different applications (Rucci *et al.*, 2012; Jung *et al.*, 2013; Funning *et al.*, 2015). Barra *et al.*, (2016) conducted a study for mapping and characterizing landslide processes in Molise, Italy, applying Differential Synthetic Aperture Radar Interferometry (DInSAR) to Sentinel-1 data for obtaining deformation maps and time series, integrated with Geographical Information System (GIS) analysis. The initial results were promising, the satellite data being able to distinguish new areas affected by landslides, updating the existent landslide map inventories. In the future, Sentinel-1 data is expected to become even more useful, due to the probability of improving the temporal resolution from 12 to 6 days, which is considerably higher in comparison to other sensors.

2. SCIENTIFIC OBJECTIVES AND STUDY AREA

The overall objective of the new research at CRMD **is to offer integrated techniques of validation and calibration performances of InSAR ground displacement products based on Sentinel-1 data, developed and tested in a variety of environments.** To achieve this aim, the workflow will ***integrate (i) Geographical Information System (GIS) multilayer analysis with (ii) InSAR-based terrain displacement maps derived from Sentinel-1 data and (iii) ground monitoring activities that can validate the InSAR data***. To do so, the ongoing research unfolds according to the following secondary objectives:

1. Identify several test areas based on geological and geomorphological mapping, diachronic cartography and on change analysis products.
2. Develop improved InSAR-based displacement products using Sentinel-1 single-polarized data focusing on selected areas.
3. Validate radar displacement products based on Global Navigation Satellite System or GNSS

and levelling geodetic measurements, as well as conventional geological and geomorphological research.

The study area is focused on one of the most complex units in terms of lithological and structural conditions, the Carpathian and Subcarpathian Prahova Valley. Prahova Valley is a landslide prone area that marks the boundary between the Eastern and the Southern Carpathians, located in a heavily faulted area and being affected by tectonic activity (Fig. 1).

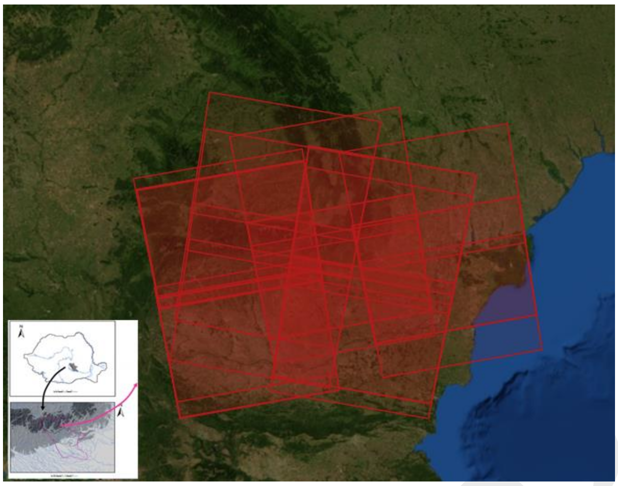

Figure 1. *Study area overlay of the Prahova Valley with respect to the footprint of achived Sentinel-1 data*

Prahova Valley is part of the external Flysch facies of Lower Cretaceous – Pliocene age. On the valley slopes, there are numerous diluvia developed starting with the first terrace of the Prahova River continuing through to upper terraces. The diluvia are mainly composed of sandstone fragments and limestone with granulation varying from fine to coarse sizes, cemented by a clay-silt matrix, which determines an accentuated instability of the slopes especially in areas without woody vegetation. The diluvium has a thickness of about 2 m. The base stratum is represented by the external Flysch facies with a high degree of fracturing and alteration to a depth of about 5 m, arranged in synclines and anticlines, especially in the tributary valleys of the Prahova River. In areas with isolated reverse faults there are deeper landslides and rock falls.

Overall, the Curvature Carpathians and Subcarpathians are susceptible to landslides as a predominant slope process, being also part of the Vrancea Seismic Region with the most active subcrustal earthquake activity in Europe (*e.g.*, Balteanu *et al.*, 2012, Radulian *et al.*, 2006). Landslides prevail in conditions of a heavily fractured flisch and broad molasses sheets with alternating layers of clay and marl, in the hilly area. Prahova Valley is also the most inhabited area of the Romanian Carpathians and Subcarpathians and an important Trans-Carpathian thoroughfare between the Balkan countries and the Orient. During the last century railway, roads, bridges and channel regulation and bank protection works were built along the Prahova Valley, together with oil and in-channel gravel exploitation. In these conditions, the urbanization development, which implies the deforestation of huge areas, will generate destabilization of slopes with cascade slope processes, especially in the Posada mountain pass and on the mountain slopes.

The field studies carried out by Professor Armas along the Subcarpathian Prahova Valley over a period of seven years, as a part of a collaborative effort on landslide vulnerability and disaster mitigation financed by the Romanian government, allowed the researchers to understand fluvial morphology and valley evolution. Channel adjustment was analyzed by comparing the old topographical maps (1864-2006), the satellite images, the orthophotomaps and the land topo-bathymetric survey performed in the summer of 2006 and 2012. The Subcarpathian area of the Prahova Valley suffered a transformation from an accumulation area to a sediment transfer zone in the present. Human negative impact amplified the natural, long-term tendency of this river for incision, narrowing and transition from a braided into a sinuous, single-thread platform pattern (Armas *et al.*, 2013). These changes have immediate and lasting effects on slope dynamics too, as the evolution of slopes is interconnected with riverbed evolution.

3. METHODOLOGY

The C-band SAR imagery is considered the ideal candidate to use in landslide monitoring along the Prahova Valley mainly because the highly-vegetated environment and steep topography. Therefore, multitemporal InSAR analysis could accurately characterize the stability of this area, being specifically designed to identify and quantify movement of potential area-based natural features (*e.g.*, rock outcrops and boulders) and localized man-made structures (*e.g.*, railroad-related objects) in different types of environments.

The InSAR techniques used in this research are as follow [for in-depth analyses, see also the invited book chapter Necsoiu and Hooper (2009)]:

• Persistent Scatterers (PS) is an InSAR technique used to detect very small displacements (mm scale) and to infer the deformation velocity – and its variation over the time – in particular for very stable (man-made) reflectors that might have independent displacements in respect to the surrounding areas (Ferretti *et al.*, 2000; Ferretti *et al.*, 2001; Hooper *et al.*, 2007).

• Small Baseline Subset (SBAS) is a complementary InSAR technique that exploits differential synthetic aperture radar interferometry (DInSAR) techniques to analyze stacks of SAR acquisitions to extract small deformations over large areas, when no point targets are identified but large, correlated displacements occur over natural targets (Berardino *et al.*, 2002; Lanari *et al.*, 2004). Since the conditions of strong nonlinearities in ground displacements affect InSAR results (Necsoiu *et al.*, 2014), destabilization of large areas could make the issue of selecting optimal areas for monitoring even more problematic. Multitemporal InSAR analysis of historical data will be performed using SBAS data, and on recent Sentinel-1 data once more than 6 SAR images will be acquired. Once more than 20 images will be available, PS analysis will be employed to derive land stability maps.

If there will be no sufficient number of stable scatterers that remain coherent during the observation period (Hanssen, 2001) and low coherence between SAR images acquired over landslides fully covered by vegetation, artificial reflectors could be necessary. The artificial rleflectors will be positionated to reduce the atmospheric effects as pointed out by (Crossetto *et al.*, 2013).

The research presents several challenges to conventional InSAR, including the following:

(i) The expected low displacement rates (*e.g.*, mm/year) and a small-time span between the first and last available radar images, requiring the use of high sensitivity InSAR methods. The vegetation cover could also represent an impediment in conducting the study.

(ii) Although radar technology is considered weather independent, there are meteorological conditions that can affect the quality of the SAR images. One phenomena that has a negative impact on the quality of the images is heavy rainfall during the passing of the satellite. Anyway, the high temporal resolution of the Sentinel-1 satellite greatly improves the chances of acquiring high quality images. In addition, there might be a limited number of months (*e.g.*, 9 months) with no snow cover. Because deep snow is an impediment in using radar interferometry technologies, heavy snowfall and prolonged periods of snow cover may reduce the time interval suitable for observations.

In our research detection and monitoring through Sentinel-1 based displacement maps will be corroborated with conventional geological and geomorphological methods. Evolution trends identified through hydraulic models, diachronic cartography and field interdisciplinary research during 2003-2006, will be correlated with complex measurements resumed in 2012, and terrestrial monitoring. The statistical methods for active landslide susceptibility mapping will be applied in combination with GIS for valley-scale analyses, whilst deterministic – or physically-based – methods will be used for local-scale analyses, either with GIS (mainly the infinite slope stability model) or without GIS (usually applied on vertical sections with circular or elliptic sliding surfaces).

For the statistical approach, we will use the weight-of-evidence method, based on the log–linear form of the Bayesian probability model, and detailed thematic layers: landslides inventory maps, slope features such as gradient, aspect, soil, etc., faults coverage, lithology, hydrological network, landuse and other parameters derived from different thematic maps and field surveys. The "predictive power" of the resulting weight maps will be tested by analyzing their success rate and prediction rate.

For the deterministic-based approach on shallow landslides susceptibility mapping, the one-dimension infinite slope stability model will be joined with a raster based GIS (ILWIS). Input parameters will consist in slope parameters (obtained from DEM processing), hydrological components (based on groundwater table mapping), and the geotechnical background (soil cohesion, unit weight and internal friction angle for the geological formations). The needed values will be obtained from scientific literature in the field, or collected from mines (mining and drilling) and own field studies. The model can be used in GIS software, because the calculation is done on a pixel basis, each raster cell being considered individually

An important task of InSAR instability maps will be to ***monitor landslides*** at a high accuracy level. Best outcomes will be obtained with multi-temporal SAR to measure displacement rates or expected landslides velocities anticipated from historical knowledge, using intensity – and coherence-tracking and cross-correlation techniques

For evaluating the results obtained by InSAR techniques, our partners from the Technical University of Civil Engineering of Bucharest will design a tracking network, following the principles of its determination with GNSS technology but also the principles used to monitor movements. Points belonging to this network will be considered "safe", stable with no changes in position over time. This will provide a monitoring reference network that will be connected to the reference system WGS84/ETRS89. Other points evenly distributed in the area of interest will be used as tracking points, points that will form the basis of monitoring. The network with stable ground points materialization and tracking points will be chosen on surfaces with geomorphological significance (*e.g.*, bridge terrace, slopes and landslide glacis) to monitor landslide processes at different spatial and temporal scales of manifestation. To obtain reliable and accurate results, the static GNSS method occupation for positioning determination will be used.

Monitoring landslides will conduct to an analysis on two references. An analysis in 2D space monitoring level (planimetric reference) and altimetric monitoring (altimetric reference). The altimetric monitoring will be made also using the classical method of geodetic levelling that provides superior accuracy to any other method (Brigante *et al.*, 2012). Positioning using GNSS technology gives 3D geometrical solutions while precise levelling method only on altitude. However, the precise levelling method for vertical monitoring can be used as an alternative method for determining the deformation in the space with one dimension.

The collaboration between the Technical University of Civil Engineering of Bucharest and the University of Bucharest will emphasize validating internal and ecological consistency of InSAR displacement products and will lead to a scientific progress via the quantification (through separation of noise from relevant information) of slope dynamics in a tectonic active area.

All these is sought to increase the Romanian research and development competitiveness by creating a niche in slope instability studies, and combining spatial technologies with ground monitoring.

4. EXPECTED RESULTS

The outcomes of the study are (a) high resolution topical digital maps; (b) simulation maps, and (c) a detailed data base of changes in vertical topography, *i.e.* all point coordinates (latitude, longitude), and associated velocity (mm/yr), coherence, h_precision (m), v_precision (mm), height correction (m), and total displacement (mm), correlated and validated with ground displacement products and results from geomorphological and geological maps. We will deliver also quantitative statistical approaches that compare the spatial distribution of landslides with most relevant and mutually independent predictive variables, using the log–linear form of the Bayesian probability model. The final susceptibility logit map will compare to the safety factors resulted from applying the one-dimensional deterministic slope stability model (infinite slope model) in different dry and saturated scenarios. Specifically, time-series changes of land elevation and slope aspect variations determined via radar interferometry will help identify potential instability areas as a response to natural and human disturbances.

These outcomes will help to better address slope instabilities that produce landslides disasters, and better understand geomorphic processes through validated measurements underlying scientific models.

Spatial embedding of validated InSAR ground displacement products **will also permit GIS integration and correlation of results with all environmental features of a specific place, creating an integrated model with a focus on simplicity, usability and efficiency. This model could help to the awareness of problems arising from slope instabilities and could be used by local stakeholders and authorities for an action concept and risk mitigation plan within communities at risk**. Bridging the gap between scientists and practitioners is the great challenge in the need to develop effective and efficient strategies for landslide risk mitigation and we believe that our research could be a successful way to integrate science and practice.

5. CONCLUSION

The research is relevant through the solutions involving monitoring of instable slope systems, which will improve the current methods of terrestrial detection and the complex validation of satellite-based InSAR displacement products. We expect that our research results will have also a socio-economic impact in helping human settlements reducing vulnerability to landslides.

REFERENCES

Armaş I. (2011), Weights of evidence method for landslide susceptibility mapping. Prahova Subcarpathians, Romania, *Natural Hazards*, 60, 3, 937-950.

Armaş I., Gogoase Nistoran D., Osaci-Costache G., Brasoveanu L. (2013), MORPHO-DYNAMIC EVOLUTION PATTERNS OF SUBCARPATHIAN PRAHOVA RIVER (ROMANIA), Catena, 100:83-99.

Armaş I., Vartolomei Fl., Stroia Fl. (2014), Landslide susceptibility deterministic approach using geographical information systems: application to Breaza city, Romania, *Natural Hazards*, 70(2), 995-1017

Bălteanu D., Jurchescu M., Surdeanu V., Ionita I., Goran C., Urdea P., Rădoane M., Rădoane N., Sima M. (2012), Recent landform evolution in the Romanian Carpathians and Pericarpathian regions, in Lóczy D., Stankoviansky M., Kotarba A. (eds.) Recent Landform Evolution. The Carpatho-Balkan-Dinaric Region, Springer, 249-286.

Barra A, Monserrat O, Mazzanti P, Esposito C, Crosetto M, Scarascia Mugnozza G. (2016), First insights on the potential of Sentinel-1 for landslides detection. Geomatics, Natural Hazards and Risk. Apr 1:1-0.

Berardino, P., Fornaro, G., Lanari, R., and Sansosti, E. (2002), A new algorithm for surface deformation monitoring based on small baseline differential SAR interferograms. IEEE Transactions on Geoscience and Remote Sensing, 40(11):2375–2383.

Brigante R, Radicioni F, Stoppini A, Fornaro F, Bovenga F, & Nitti OD, (2012). SAR, GNSS and leveling comparision on multi-annual series for the study of landslide surface deformation http://lnx.mimos.it/mimos_decennale/Proceedings/SicurezzaTerritorio_08_Stoppini.pdf

CRED (2015). Retrieved from International Disaster Database: http://www.cred.be/emdat.

Crosetto M, Gili, JA, Monserrat O., Cuevas-Gonźalez J. Serrat D. (2013), Interferometric SAR monitoring of the Vallcebre landslide (Spain), using corner reflectors, Nat. Hazards Earth Syst. Sci., 13, 923-933, http://nat-hazards-earth-syst-sci.net/13/923/2013/nhess-13-923-2013.pdf

Ferretti, A., Prati, C., & Rocca, F. (2000). Nonlinear subsidence rate estimation using permanent scatterers in differential SAR interferometry. IEEE Transactions on Geoscience and Remote Sensing, 38(5):2202-2212.

Ferretti, A., Prati, C., & Rocca, F. (2001). Permanent scatterers in SAR interferometry. IEEE Transactions on geoscience and remote sensing, 39(1):8-20.

Funning GJ, Floyd M, Walters RJ, Elliott JR, Wright TJ, Marinkovuc P, Larsen Y. (2015). Complexity in the coseismic fault geometry and in the postseismic slip distribution of the South Napa earthquake, from Sentinel-1A InSAR and near-field GPS data. Seismol. Soc. of Am. Meet., Pasadena, Calif. 2015 Apr.

Hanssen, R. (2001), Radar interferometry, Kluwer Academic Publishers, Dordrecht (The Netherlands).

Hilley, G. E., Burgmann, R., Ferretti, A., Novali, F., and Rocca, F. (2004), Dynamics of slow-moving landslides from Permanent Scatterer analysis, Science, 304 (5679), 1952–1955.

Hooper, A., Segall, P., & Zebker, H. (2007). Persistent scatterer interferometric synthetic aperture radar for crustal deformation analysis, with application to Volcán Alcedo, Galápagos. Journal of Geophysical Research: Solid Earth, 112(B7).

Jung HS, Lu Z, Zhang L. (2013). Feasibility of along-track displacement measurement from Sentinel-1 interferometric wide-swath mode. Geoscience and Remote Sensing, IEEE Transactions on. Jan; 51(1):573-8.

Lanari, R., Mora, O., Manunta, M., Mallorquí, J.J., Berardino, P., and Sansosti, E. (2004). A small-baseline approach for investigating deformations on full-resolution differential SAR interferograms. *IEEE* TGRS 42 (7), 1377-1386.

Lee S., Choi J., Min K. (2002). Landslide susceptibility analysis and verification using the Bayesian probability model, Environmental Geol., 43, 1-2.

Metternicht, G., Hurni, L., Gogu, R. (2005). Remote sensing of landslides: An analysis of the potential contribution to geo-spatial systems for hazard assessment in mountainous environments. Remote sensing of Environment, 98(2): 284-303.

Micu M., Chendeş V., Sima M., Bălteanu, D., Micu, D., Dragotă, C. (2010), A multi-hazard asssessment in the Bend Carpathians of Romania, în vol. (Editori: Glade, T., Casagli, N., Malet, J.P) Mountain Risks: bringing science to the society, CERG Editions, Strasbourg.

Micu, M., Bălteanu, D. (2009) Landslide hazard assessment in the Curvature Carpathians and Subcarpathians, Romania, Zeitschrift fur Geomorphologie, Suppl.3, 53, Stuttgart, Germany;

Micu, M., Jurchescu, M., Micu, D., Zarea, R., Zumpano, V., Bălteanu, D. (2014). A morphogenetic insight into a multi-hazard analysis: Bâsca Mare landslide dam, Landslides, DOI 10.1007/s10346-014-0519-4

Muntohar, A. S. and Liao H-J. (2010). Rainfall infiltration: infinite slope model for landslides triggering by rainstorm, *Nat Hazards*, 54:967-984.

Necsoiu M., & Hooper DM (2009). Use of Emerging InSAR and LiDAR Remote Sensing Technologies to Anticipate and Monitor Critical Natural Hazards, Invited Book Chapter in "*Building Safer Communities. Risk Governance, Spatial Planning and Responses to Natural Hazards*", Volume 58 NATO Science for Peace and Security, Series – E: Human and Societal Dynamics, Editor: U. Fra Paleo, August 2009, Pages 246-267.

Necsoiu M., Ronald I., McGinnis N., Donald I, Hooper M. (2014). New insights on the Salmon Falls Creek Canyon landslide complex based on geomorphological analysis and multitemporal satellite InSAR techniques, Landslides, 11(6):1141-1153 DOI 10.1007/s10346-014-0523-8.

Nolan M, Fatland DR. (2003). Penetration depth as a DInSAR observable and proxy for soil moisture. Geoscience and Remote Sensing, IEEE Transactions on. Mar;41(3):532-7.

Radulian M, Mândrescu N, Grecu B (2006). Seismic ground motion variability over the Bucharest area, *Acta Geodaetica et Geophysica Hungarica*, 41(3-4): 361-368.

Rucci A, Ferretti A, Guarnieri AM, Rocca F. (2012). Sentinel 1 SAR interferometry applications: The outlook for sub millimeter measurements. Remote Sensing of Environment. May 15;120:156-63.

Sarkar S, Kanungo DP. (2004). An integrated approach for landslide susceptibility mapping using remote sensing and GIS. *Photo Eng Remote Sens* 70:617-625

Thaiyuenwong, S. and Maireang, W. (2010). Triggered-Rainfall Landslide Hazard Prediction, Research and Development J., 21, 2, 43-50.

UN – ISDR (2004). *Living with Risk. A Global Review of Disaster Reduction Initiatives*. United Nations, Geneva, p. 430. http://www.unisdr.org/eng/about_isdr/bd-lwr-2004-eng.htm (accessed 12 November 2011).