ESTABLISHING LANDSLIDE EARLY WARNING SYSTEM USING RAINFALL THRESHOLDS IN THE PROVINCE OF ALBAY, PHILIPPINES

Mark Niño L. Miraballes
Supervising Geologist, MGB-V

Abstract

The threshold-based Landslide Early Warning System (LEWS) is an innovation to the existing MGB scheme of providing landslide warning to the Local Government Units (LGUs) in Albay. It aims to provide accurate, easy-to-interpret, timely, and regularly updated landslide warning information. The author, with the help of MGB-V, designed the LEWS and had it tested during Typhoon Ulysses in November 2020. The results were then used in the calibration of rainfall thresholds for better performance.

The LEWS is based on rainfall thresholds derived from the analysis of rainfall and landslide initiation. The calculation of thresholds focused on two (2) rainfall parameters, the rainfall intensity, and the event rainfall. It also considered the geologic and geomorphic conditions in Albay and divided the province into different warning landscapes. After determining the rainfall thresholds, subsequent calibration was made using a new rainfall-landslide dataset.

One of the key objectives of the LEWS is to empower LCEs and LDRRMOs in making critical decisions concerning landslide preparedness and safety measures. It also seeks to contribute to the long-term goal of reducing casualties due to landslides. To ensure its success and sustainability, continued engagements to strengthen partnerships and promote collaborations with LGUs and other key stakeholders should be pursued. With concerted efforts and with resources focused on attaining one shared goal, the project could be truly instrumental in reducing landslide casualties.

Introduction

In the Philippines, the Province of Albay is considered one of the areas that have long been affected by landslides. Some of the past landslide disasters have brought considerable damage and claimed hundreds of lives in Albay. The most recent of these happened during Tropical Depression (TD) “Usman” on December 28-29, 2018, where at least 15 people were killed and another 10 were injured.

For the past seven (8) years, MGB-V flood and landslide threat advisories have been regularly issued to both Barangay and Municipal/City LGUs during the conduct of field mapping, and in times of impending tropical cyclones. The issuance of both flood and landslide threat advisories normally ensues after the Pre-Disaster Risk Assessment (PDRA) meeting called for by the Regional Disaster Risk Reduction and Management Council (RDRRMC), through the Office of Civil Defense V (OCD-V). It is quite unfortunate and alarming, that even with the issuance of these threat advisories, landslide casualties continue to happen.

Feedback and comments from some Local Disaster Risk Reduction and Management Officers (LDRRMOs) in Bicol, as expressed during meetings and forums, showed the inherent difficulty in using warning information contained in the MGB-V landslide threat advisories, since it doesn’t tell when landslides may initiate. LGUs have also complained about the unavailability and inaccessibility of real-time rainfall data, which can be used in combination with the arguably ambiguous landslide warning information, as the basis of their respective evacuation protocols and contingency plans. On the other hand, it may also be possible that some of these LGUs might have failed to utilize the warning information provided to them promptly and properly. In this case, it is apparent that the problem now lies in the operational use of warning information. These, together with several socio-political factors, could be the very reasons why several casualties continue to be recorded because of landslides.

Study Area

The Province of Albay is one of the six provinces that comprise the Bicol Region, which is located on the southern tip of Luzon Island. Albay lies on the south-central portion of Bicol and is bounded by the Province of Camarines Sur on the north. Its south margins border the Province of Sorsogon, while bodies of water share its western and eastern boundaries. The Burias Pass borders Albay to the west, and the Philippine Sea together with Lagonoy Gulf and Albay Gulf bound its eastern margins. Albay has a total land area of 2,554.06 square kilometers (About Albay, n.d) and consists of 15 municipalities and 3 cities, including Legazpi City as its capital. The island Municipality of Rapu-Rapu is the only LGU that is geographically separated from mainland Albay. The topography of Albay is largely characterized by high relief volcanic and mountainous terrains with slopes ranging from gentle to very steep (Fig. 1). The flat to nearly flat areas are mostly located in the central part of Albay (Albay floodplain), with some alluvial and coastal plains sporadically distributed within the province.

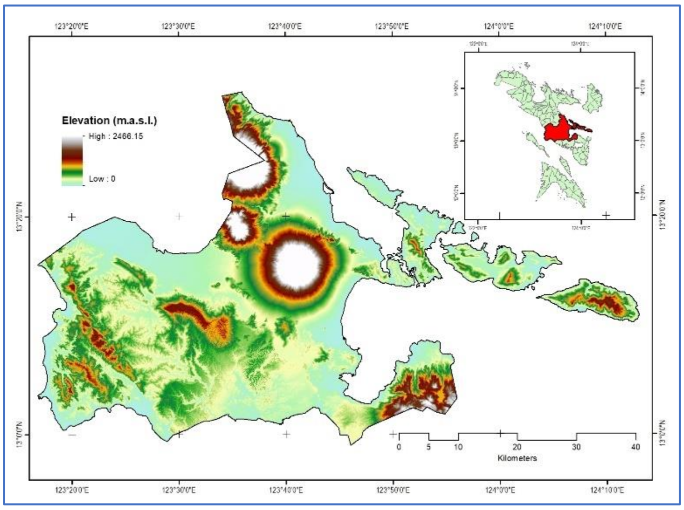

Fig. 1 The study area with elevation values in m.a.s.l.

For this study, the author subdivided the province into 6 geologic landscapes. These are the Albay West Coast (AWC), Albay Syncline (AS), Eroded Volcanic Landscape (EVL), Ophiolitic Belt (OB), Mayon Volcano (MV), and Alluvial Areas (AA). AWC is composed of low to moderate relief terrain, with moderately steep to very steep slopes, and underlain by igneous rocks of ultrabasic to intermediate composition. It occupies the westernmost portion of the province, together with a small portion of central Albay. The AS landscape is characterized by low to high relief terrain, having slopes ranging from gentle to very steep, with sedimentary rocks composed of calcareous siltstone-shale-sandstone and limestone. It covers parts of western and southern Albay and occupies most of the southwestern portion. The EVL consists of low to very high relief inactive and potentially active volcanic centers that include Mt. Malinao, Mt. Masaraga, and the Pocdol Mountains, having steep to very steep slopes. The underlying rocks are composed of basic to acidic volcanic flows and a wide variety of volcaniclastics. EVL covers most of the northwestern and southeastern portions and a part of central Albay. MV is essentially the volcanic edifice of Mayon, which occupies central Albay, while the AA covers relatively flat areas and is underlain by recent alluvial deposits.

Based on the Modified Coronas' Climate Classification of PAGASA, the Philippine climate can be divided into 4 types. The latest climate map of the Philippines shows that Albay lies within the Type II climate, which is described as having no dry season with pronounced maximum rains for the period December to February. It is said that there is no dry month for this type of climate and that the minimum amount of rain is expected over the months of March, April, and May (Climate of the Philippines, 2014).

Methodology

The empirical and probabilistic method proposed by J. Huang et. al. (2015) was adopted in determining the rainfall thresholds for the LEWS. The method calculates multiple thresholds and delineates probability zones. The rainfall parameters used are the rainfall intensity (mm/day) and the total event rainfall (combined 3-day cumulative rains and landslide event rainfall). Correlation and regression analysis were then used in calculating the rainfall threshold.

Historical rainfall data were gathered from three (3) PAGASA gauging stations: the SLPRD Synoptic station in Legazpi City, the PAGASA Agro meteorology station in Guinobatan, and the BRBFFWC station in Buhi, Camarines Sur. A rainfall database containing daily rainfall for the past 32.5 years (January 1, 1989, to June 30, 2020) was prepared for subsequent analysis. Meanwhile, a landslide catalog containing information on the occurrence date, location, type of landslide, rock type, etc., was also prepared for separate analysis. Both rainfall database and landslide catalog were independently analyzed before the needed bivariate analysis, which involved the pre-selection of significant rainfall events and the determination of cumulative rainfall (3 days, 5 days, and 10 days) before the landslide occurrence.

To check the accuracy and performance of these thresholds, calibration was made using a new set of rainfall and landslide data covering three (3) months. Both rainfall and landslide data from October 1, 2020, to December 31, 2020, were analyzed using correlation and regression methods.

Results

Using lines of best fit derived from the rainfall-landslide correlation, three (3) threshold lines were graphically drawn to delineate probability zones, representing a range of probabilities (in percent) for landslide occurrence. A lower threshold represents the minimum threshold, while an upper threshold corresponds to the maximum threshold. An intermediate threshold line represents the median or middle threshold (Fig. 2).

The calculated rainfall thresholds are as follows; 200 mm/day (intensity) and 260 mm. (total event rainfall) for the lower threshold, 280 mm/day and 380 mm. for the middle threshold, and 400 mm/day and 525 mm. for the upper threshold. These thresholds were subsequently tested using a new set of rainfall-landslide datasets (October to December 2020).

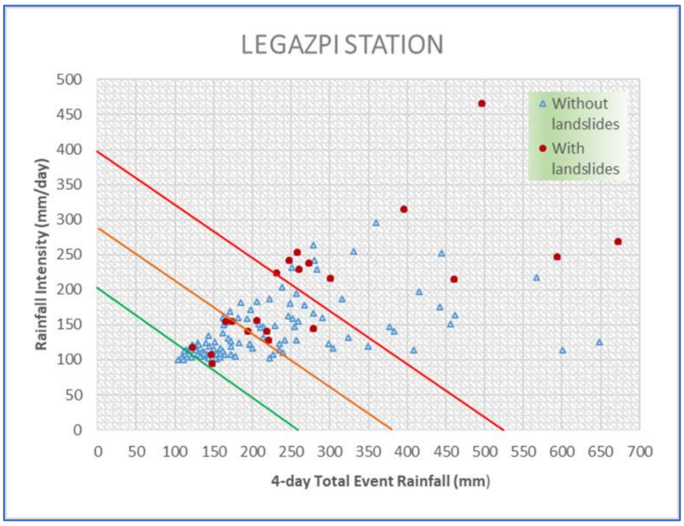

Fig. 2 Scatter plot of rainfall events and the empirical threshold lines.

Using the October to December 2020 rainfall-landslide dataset, the author was able to calibrate the initially identified rainfall thresholds and identified a new set of thresholds for 2 warning landscapes. The new set of thresholds are as follows: 130 mm/day and 200 mm. for the lower threshold, 185 mm/day, and 295 mm. for the middle threshold, and 260 mm/day and 405 mm. for the upper threshold. These thresholds are only applicable to the Albay Syncline and Eroded Volcanic Landscape units (Fig. 3).

WARNING LANDSCAPE	CALIBRATED RAINFALL THRESHOLDS (I_d - E_t)		
	Lower bound	Middle	Upper bound
Albay West Coast	200 mm^{-d}; 260 mm	285 mm^{-d}; 380 mm	400 mm^{-d}; 525 mm
Albay Syncline	130 mm^{-d}; 200 mm	185 mm^{-d}; 295 mm	260 mm^{-d}; 405 mm
Eroded Volcanic Landscape	130 mm^{-d}; 200 mm	185 mm^{-d}; 295 mm	260 mm^{-d}; 405 mm
Ophiolitic Belt	200 mm^{-d}; 260 mm	285 mm^{-d}; 380 mm	400 mm^{-d}; 525 mm

Fig. 3 Calibrated rainfall thresholds for the different warning landscape units.

The new set of thresholds is presently used in the issuance of landslide warning bulletins to Albay. The landslide bulletins are sent to the Albay Public Safety and Emergency Management Office (APSEMO) through email and regularly posted on the MGB-V website every 12 hours until necessary. Moreover, the study also comes with a schematic diagram for easy replication in other areas (Fig. 4). It should be noted, however, that landslide early warning systems are location specific.

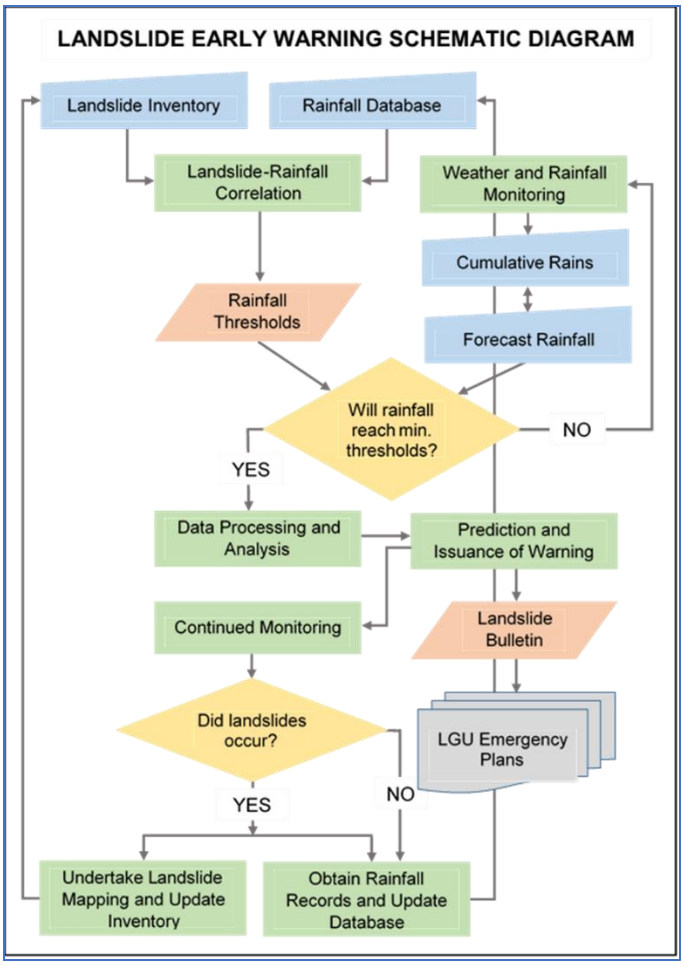

Fig. 4 Calibrated rainfall thresholds for the different warning landscape units.

Challenges

Although the threshold values were objectively defined using empirical and probabilistic methods, three issues still need to be addressed. One of these is that the calculated threshold values for the whole Province of Albay were only derived from the Legazpi rainfall dataset. Another one is the 100 mm cut-off used by the scholar in selecting the rainfall events for analysis. Since it has been observed that less than 100 mm of daily rainfall is capable of triggering landslides. And even though some known < 100 mm rainfall events that have triggered landslides were included in the analysis, the lack of information on the date and time of landslide occurrence still resulted in data uncertainty. And last but not the least, the calculated thresholds do not consider sufficient lead time for preparation and evacuation since the thresholds are based on daily rainfall intensity and total event rainfall.

Moreover, the rainfall used in the warning bulletin is 12-hr forecast rainfall, instead of the more ideal real-time rainfall values. Albay's terrain configuration, the underdeveloped road network in the mountainous areas, and the challenges in communicating warning information are also some of the important considerations in identifying the rainfall thresholds to be used in an operational LEWS.

Conclusions and Recommendations

The LEWS is yet to be evaluated for its performance using recent supplemental and independent datasets. In the meantime, however, the calibrated rainfall thresholds can already be used in the issuance of landslide bulletins, and for operational use in the landslide early warning system in Albay. When sufficient data are collected in the future, statistical testing and validation can already be used to enhance the performance of these rainfall thresholds.

The iterative nature of the threshold-based LEWS in Albay allows for the enhancement of the entire system through strategies such as adopting alternative methods and technological advancements, introducing more effective and reliable processes, and the formulation of enabling mechanisms and supporting policies. With continued testing and improvement, the MGB-V LEWS can therefore significantly contribute to reducing landslide casualties.

References

Aleotti, P. (2004). A warning system for rainfall-induced shallow failures. Engineering Geology. 73. 247-265. https://doi.org/10.1016/j.enggeo.2004.01.007

Baum, R., Godt, J. & Savage, W. (2010). Correction to “Estimating the timing and location of shallow rainfall-induced landslides using a model for transient, unsaturated infiltration”. Journal of Geophysical Research. 115. https://doi.org/10.1029/2009JF001321

Berti, M., Martina, M. L. V., Franceschini, S., Pignone, S., Simoni, A. & Pizziolo, M. (2012). Probabilistic rainfall thresholds for landslide occurrence using a Bayesian approach, J. Geophys. Res., 117, F04006. https://doi.org/10.1029/2012JF002367

Cannon, S. H., Boldt, E. M., Laber, J. L. (2011). Rainfall intensity–duration thresholds for postfire debris-flow emergency-response planning. Nat Hazards 59, 209–236. https://doi.org/10.1007/s11069-011-9747-2

Caracciolo, D., Arnone, E., Conti, F. & Noto, L. (2017). Exploiting historical rainfall and landslide data in a spatial database for the derivation of critical rainfall thresholds. Environmental Earth Sciences. 76. 1-16. https://doi.org/10.1007/s12665-017-6545-5

Cardinali, M., Galli, M., Guzzetti, F., Ardizzone, F., Reichenbach, P. & Bartoccini, P. (2006). Rainfall induced landslides in December 2004 in South-Western Umbria, Central Italy: Types, extent, damage and risk assessment. Natural Hazards and Earth System Science. 6. https://doi.org/10.5194/nhess-6-237-2006

Carlà, T., Intrieri, E., Raspini, F., Bardi, F., Farina, P., Ferretti, A., Colombo, D., Novali, F. & Casagli, N. (2019). Perspectives on the prediction of catastrophic slope failures from satellite InSAR. Scientific Reports. 9. https://doi.org/10.1038/s41598-019-50792-y

Chleborad, A.F. (2003). Preliminary evaluation of a precipitation threshold for anticipating the occurrence of landslides in the Seattle, Washington. Area: U. S. Geological Survey Open-File report 03-463.

Collison, A.J.C. & Anderson, M.G. (1996). Using a combined slope hydrology/stability model to identify suitable conditions for landslide prevention by vegetation in the humid tropics. Earth Surf. Process. Landforms, 21: 737747.https://doi.org/10.1002/(SICI)10969837(199608)21:8<737:AID-ESP674>3.0.CO;2-F

Crosta, G. B. & Frattini, P. (2003). Distributed modelling of shallow landslides triggered by intense rainfall, Nat. Hazards Earth Syst. Sci., 3, 81–93. https://doi.org/10.5194/nhess-3-81-2003.

DiBiagio, E. & Kjekstad, O.: Early Warning, Instrumentation and Monitoring Landslides, 2nd Regional Training Course, RE- CLAIM II, Phuket, Thailand, 29 January–2 February 2007, 1–24, 2007. Available from: http://www.adpc.net/V2007/Programs/UDRM/PROGRAMS_PROJECTS/RECLAIMIII/Downloads/RECLAIMProceedings

Ghosh, J., Bhattacharya, D., Boccardo, P. & Samadhiya, N. K. (2010). A landslide hazard warning system. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives. 38. 261-265.

Guo, Z., Yin, K. & Gui, L. (2019). Regional rainfall warning system for landslides with creep deformation in Three Gorges using a statistical black box model. Sci Rep 9, 8962. https://doi.org/10.1038/s41598-019-45403-9

Guzzetti, F., Peruccacci, S. & Rossi, M. (2008). The rainfall intensity–duration control of shallow landslides and debris flows: An update. Landslides 5, 3–17. https://doi.org/10.1007/s10346-007-0112-1

Huang, J., Ju, N., Liao, Y. & Liu, D. (2015). Determination of rainfall thresholds for shallow landslides by a probabilistic and empirical method. Natural Hazards and Earth System Sciences. 15. https://doi.org/10.5194/nhess-15-2715-2015

Intrieri, E., Gigli, G., Casagli, N. & Nadim, F. (2013). Landslide early warning system: Toolbox and general concepts. Natural Hazards and Earth System Sciences. 13. 85-90. https://doi.org/10.5194/nhess-13-85-2013

Intrieri, E., Gigli, G., Mugnai, F., Fanti, R. & Casagli, N. (2012). Design and implementation of a landslide early warning system. Engineering Geology. 147-148. 124-136. https://doi.org/10.1016/j.enggeo.2012.07.017

IPCC. (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on

Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Jakob, M., Owen, T. & Simpson, T. (2012). A regional real-time debris-flow warning system for the District of North Vancouver, Canada. Landslides 9, 165–178. https://doi.org/10.1007/s10346-011-0282-8

Kulatunga, U. (2010). Impact of Culture towards Disaster Risk Reduction, International Journal of Strategic Property Management, 14:4, 304-313, DOI: 10.3846/ijspm.2010.23

Lepore, C., Arnone, E., Noto, L. V., Sivandran, G. & Bras, R.L. (2013). Physically based modeling of rainfall-triggered landslides: A case study in the Luquillo forest, Puerto Rico. Hydrol. Earth Syst. Sci. https://doi.org/10.5194/hess-17-3371-2013

Martelloni, G., Segoni, S. & Fanti, R. (2012). Rainfall thresholds for the forecasting of landslide occurrence at regional scale. Landslides 9, 485–495. https://doi.org/10.1007/s10346-011-0308-2

Medina-Cetina, Z. & Nadim, F. (2008). Stochastic design of an early warning system. Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards. 2. 223-236. https://doi.org/10.1080/17499510802086777

Mercogliano, P., Segoni, S., Rossi, G., Sikorsky, B., Tofani, V., Schiano, P., Catani, F. & Casagli, N. (2013). Brief communication: A prototype forecasting chain for rainfall induced shallow landslides. Natural hazards and earth system sciences. 13. 771-777. https://doi.org/10.5194/nhess-13-771-2013

MGB-V. (2019). Incident Report: December 2018 heavy to torrential rains brought by Tropical Depression “Usman” and the Tail End of a Cold Front (TECF)

Nolasco-Javier, D., Kumar, L. & Tengonciang, A.M.P. (2015). Rapid appraisal of rainfall threshold and selected landslides in Baguio, Philippines. Nat Hazards 78, 1587–1607. https://doi.org/10.1007/s11069-015-1790-y

OCD V. (2019). Memorandum for the CDA with Subject: SITREP # 21 – LPA (Former TD “USMAN”)

Piciullo, L., Gariano, S. L., Melillo, M., Brunetti, M., Peruccacci, S., Guzzetti, F. & Calvello, M. (2017). Definition and performance of a threshold-based regional early warning model for rainfall-induced landslides. Landslides. 14. 995-1008. https://doi.org/10.1007/s10346-016-0750-2

PHIVOLCS. (2018). DYNASLOPE Project. https://www.phivolcs.dost.gov.ph/index.php/landslide/dynaslope-project

Provincial Government of Albay (n.d.). About Albay. Retrieved August 10, 2020, from http://albay.gov.ph/about/

Rossi, G., Catani, F., Leoni, L., Segoni, S., & Tofani, V. (2013). HIRESSS: A physically based slope stability simulator for HPC applications. Natural Hazards and Earth System Science, 13(1), 151–166. https://doi.org/10.5194/NHESS-13-151-2013

Schenato, L., Palmieri, L. & Camporese, M. (2017). Distributed optical fiber sensing for early detection of shallow landslides triggering. Sci Rep 7, 14686. https://doi.org/10.1038/s41598-017-12610-1

Segoni, S., Rossi, G. & Catani, F. (2012). Improving basin scale shallow landslide modelling using reliable soil thickness maps. Natural Hazards. 61. 85-101. https://doi.org/10.1007/s11069-011-9770-3

Segoni, S., Leoni, L., Benedetti, A., Catani, F., Righini, G., Falorni, G., & Gabellani, S., Rudari, R., Silvestro, F. & Rebora, N. (2009). Towards a definition of a real-time forecasting network for rainfall induced shallow landslides. Natural hazards and earth system sciences. 9. 2119-2133. https://doi.org/10.5194/nhess-9-2119-2009

Segoni, S., Rosi, A., Rossi, G., Catani, F. & Casagli, N. (2014). Analyzing the relationship between rainfalls and landslides to define a mosaic of triggering thresholds for regional scale warning systems. Natural Hazards and Earth System Sciences, 14, 2637-2648. https://doi.org/10.5194/nhessd-2-2185-2014

Simoni, S., Zanotti, F., Bertoldi, G. & Rigon, R. (2008). Modelling the probability of occurrence of shallow landslides and channelized debris flows using GEOtop-FS. Hydrological Processes. 22. 532 - 545. https://doi.org/10.1002/hyp.6886

Thiebes, B. (2012). Landslide Analysis and Early Warning Systems: Local and Regional Case Study in the Swabian Alb, Germany. Landslide Analysis and Early Warning Systems. https://doi.org/10.1007/978-3-642-27526-5

Tiranti, D., & Rabuffetti, D. (2010). Estimation of rainfall thresholds triggering shallow landslides for an operational warning system implementation. Landslides 7, 471–481. https://doi.org/10.1007/s10346-010-0198-8

Thomas, A. (1996) ‘What is development management?’, Journal of International Development, vol. 8, no. 1, pp. 95–110.

UNISDR. (2006). Global Survey of Early Warning Systems: An assessment of capacities, gaps and opportunities toward building a comprehensive global early warning system for all-natural hazards. Available from: https://www.unisdr.org/we/inform/publications/3612

Wilkinson, P.L., Anderson, M.G. and Lloyd, D.M. (2002), An integrated hydrological model for rain-induced landslide prediction. Earth Surf. Process. Landforms, 27: 1285-1297. https://doi.org/10.1002/esp.409