Landslides
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Jiří Zvelebil · Jiří Šíma · Vit Vilímek

Geo-risk management for developing countries—vulnerability to mass wasting in the Jemma River Basin, Ethiopia

Abstract A progress report of the M141 IPL project is presented. Conceptual and applied analyses bearing on engineering geological, hydrogeological mapping, and zoning of vulnerability to mass wasting were conducted for nearly a 16,000-km^2 area of the Jemma River basin, central Ethiopian highlands. Work was aimed at the specific modification of current methodology and its practical field testing, user-oriented information dissemination, and training of Ethiopian staff in geo-hazard assessment. Also, environmental protection studies and water resources management to improve food and sanitary security were provided. An alternative, conceptual energy-process and land unit-oriented and satellite images implementing method was developed to substitute for the inadequacy of information by regular field check and regular inventory of risky phenomena. It is necessary to implement a novel, complex systems paradigm to tackle vulnerability and risks in couplings of nature and human systems. This is discussed together with emphasis on user-oriented communication and building of geo-risk warning and management systems based on bottom-up, contextual approach.

Keywords Natural hazards · Landslides · Capacity building · Central highlands of Ethiopia

Introduction

The general, long-term aim of the M141 Project "Geo-Risk Management for Third World Countries—Mapping and Assessing of Risky Geo-Factors for Land Use" is to conduct conceptual and applied analyses and information dissemination to enhance geo-risk management for better resilience and adaptation of local societies and geo-ecosystems in developing countries. Interactions of humans and natural systems have resulted in the formation and development of coupled human and natural systems (CHANS). Within those systems, society and nature act not only as the hazard inducer but also as the hazard recipient. Moreover, the CHANS approach challenges traditional planning and management assumptions and strategies for natural resources and management (Liu et al. 2007).

In the developing countries, an ever-increasing human population pressure combines with aggravated effects of global climate change, while risk management is not adequately developed. Almost 96% of deaths from floods, landslides, and other natural disasters occurred in third world countries (Freeman et al. 2003).

Ethiopia is an example of a country which suffers from population and resources pressure on one side and from an intense influence of geo- and climatic factors on development of its various societies. A joint, Czech–Ethiopian study was conducted in the central highlands of Ethiopia and on their proximity with the East-African Rift. It aimed the case-specific modification of current methodology and its practical field testing to user-oriented information dissemination and training of Ethiopian staff in geo-hazard assessment, environmental protection studies, and water resources management to improve food and sanitary security. Results obtained are showing that even simple but on basic geomorphological and engineering geological idea-based models used under the shortage of filed-checked data can yield satisfactory results.

Mass wasting vulnerability in Jemma River basin, Ethiopia

Engineering geological, hydrogeological maps and zoning of vulnerability to mass wasting were compiled for an approximately 16,000-km^2 area of the Jemma River basin. This area is typical with various indications of land degradation that arose as a result of rapid land-cover changes caused by a growing population and extensive farming pressures, during the last decades. At the same time, the infrastructure and settlements are exposed to hazards due to mass wasting, including landslides and rockfalls (Fig. 1) These processes are due to geomorphologically young, high-energy relief of deep erosion dissections of the plateau (Fig. 2) and by active seismic–tectonic and seismic–gravitational processes occurring especially at the rim of the rift valley.

Because of the mapping scale of 1:250,000 and the inadequacy of information by regular field inventory of events and their conditions to enable regular statistical analyses and to identify of the generic types of events and factors affecting their occurrence, an alternative, conceptual energy-process and land unit-oriented method was chosen. The geology and geomorphology of the Jemma River basin has also not been previously or adequately studied on a regional basis. Therefore, our mapping also included unification of site- or small-scale-oriented geological information by different authors for compiling a regional geological map and for conducting geomorphological investigations.

The alternative model for compiling of the engineering geological and vulnerability maps was based on assessment of relief energy which, under supposed regionally quasihomogeneous conditions of climatic influence, has been considered the main driving force of shaping of relief by exogenic processes. The latter incorporated mainly processes of mass wasting including weathering, landslides, rockfalls, and erosion together with the types of accumulations produced by them (Fig. 3). Comprehensive use of satellite images should also compensate the relative lack of actual data by direct field checking. In order to store, merge, and spatially analyze all the complex data gathered, a geographic information system application was used.

Regional DMT, land cover, and geological data were merged together with engineering geological information from generically modeled areas to provide detailed zoning of the basic engineering geological map. Basic land units were delimited in accordance to individual scoring using local relief energy and geomechanical

Fig. 1 Opening of tension cracks in the fore field of the upper rim of the plateau above a canyon of nearly 800 m in depth, near Fiche town. Those cracks indicate active, catastrophic rock falls from columnar-jointed tertiary plateau basalts (photo Zvelebil)

properties of bedrock and soils. Negative scoring has been also added to low-energy river flood plains because of the possibility of disastrous floods. Occurrence of catastrophic floods carrying substantially increased volumes of coarse materials and boulders was indicated by abrupt, lithological–structural change observed in upper, i.e., subhistoric parts of alluvial soils. As a result, 32 classes of basic land units of the engineering geological map were indicated (Fig. 4).

Regarding the scoring of units, a simpler ranking scale having only four degrees had been statistically applied, and the region was

Fig. 2 High-energy relief in the narrow part of the nearly 250-m-deep erosional valley cut by a left side, nameless tributary of the Jemma River. Notice a high waterfall representing the difference between the local erosional basis of the plateau from the regional basis of Jemma River and its recently backward-advancing erosion. Step-like valley sides are mainly produced by differentiated morphological resistance of individual flows of basalts and rhyolites (photo Zvelebil)

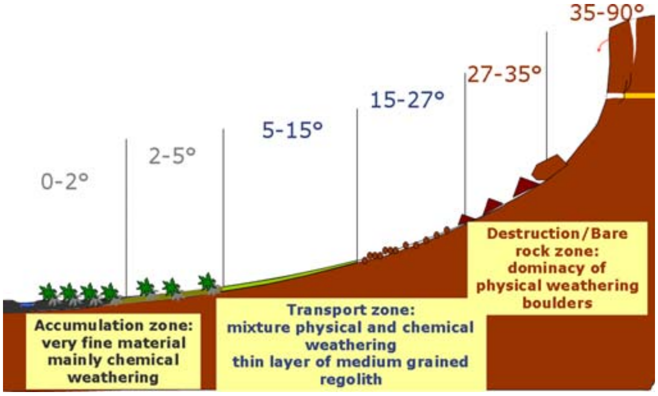

Fig. 3 Graphical scheme of the model for relief energy scoring according to slope angles: This energy is under assumed regional quasihomogeneous conditions of climatic influence, the main driving force of relief shaping by exogenic processes incorporating mass wasting

reclassified to provide the vulnerability map (Fig. 5). That map has also provided basic information about endogenous hazard. Epicenters of 68 earthquakes, which occurred in the mapped area between 1960 and 1996, have been depicted, and a prognostic map of ground-shaking intensity has been placed as its accompanying map.

Reliability of the relief energy/ground resistance, process-related method for compiling the vulnerability map was tested with encouraging results. Sites of active mass wasting documented in the field were compared with the vulnerability zoning. There has been good conformity between reality and zones of very high and high vulnerability—83.3% for landslides and 75% for rockfalls.

Engineering geological, hydrogeological, and vulnerability to mass-wasting maps compiled have provided baseline data for geoscientists, stakeholders, and investors as well as the community entity that facilitates sustainable land-use guidelines with special regards to civil engineering and urbanism as well as for local remedial projects. Recommendations for the most challenging tasks of economic geology, water resources management, and mass wasting have also been provided in explanatory texts for the maps. All results were published (Šíma et al. 2009) in the form of book that is supplemented by a DVD, enabling an interactive access to the text of the book and to all the maps.

Discussion and conclusions

The implementation of the idea-based models and the land-unit approach according to general but from the system point of view, consistent models of relations and factors ruling activity of exogenous relief-building processes, has shown itself fruitful. Together with the intensive exploitation of satellite images as the crucial source of information, they have exhibited their competency to be used in geo-risk management especially under the working conditions characterizing developing countries, i.e. lack of archive data and actual geographic and geologic maps, for example, and more or less severe restrictions of direct field checking due to time–money restrictions and/or low field accessibility.

The elaborated, relief energy/ground resistance process-related classification system is an open dynamic system which provides a conceptually unified frame for further targeted gathering, contextual ranking, and integral interpretation of complex information. However, all the work described in this paper is only an initial

Fig. 4 Basic land units of the regional, engineering geological map at a scale of 1:250,000 fixed in accordance to scoring based on relief energy and ground persistency due to geomechanical properties of bedrock and soils

SOIL COVER > 2 m

Stratigraphic unit	Relief energy			Approximative geomechanical parameters			
Origin	low	medium	high	USCS	γ (kN/m³)	c_u (kPa)	φ_u (°)
Quaternary							
alluvial				SC + ML GM + SM	18.5 - 20 18 - 19	70 - 80 0 - 10	8 - 15 28 - 35
colluvial				ML + CH	20 - 20.5	40 - 80	0 - 5
residual				MH + CH	20.5 - 21	50 - 80	0

BEDROCK

Stratigraphic unit	Relief energy			Rock mass strengh (MPa)			
Petrology	low	medium	high	very weak < 5	weak 5 - 25	medium 25 - 50	strong 50 - 150
Quaternary							
QV4 *ashes,tuffs*				●			
QV3 *ignimbrites*					●		
QV2 *basalts*						●	
QV1 *basalts*						●	
Tertiary							
TV7 *plateau basalts*						●	
TV6 *trachytes*						●	
TV5 *basalts*							
TV4 *rhyolites*					●		
TS *conglom. sandstones, tuffits*				●	●		
TV3 *basalts*							●
TV2 *tuffs, basalts*					●		
TV1 *basalts*							●
Mesozoic							
MeUSa *sandstones*				●	●		
MeMu-Si *mudstones, siltstones*				●	●		
MeLi *limestones*						●	
MeGy *gypsum, shales*				●	●		
MeLSa *sandstones*					●	●	

step for a more demanding task of geo-risk management because the latter includes the well-known sequence of vulnerability, hazard, and risk assessments, followed by prevention/remedy tasks. Moreover, all of these items have to be challenged with regard to a new paradigm of CHANS.

Nowadays, the CHANS are changing traditional planning and management assumptions and strategies for natural resources and management by the emphasizing of complex, dynamic features of the couplings of social and natural system across spatial, temporal, and organizational scales (Liu et al. 2007). Based on the complex

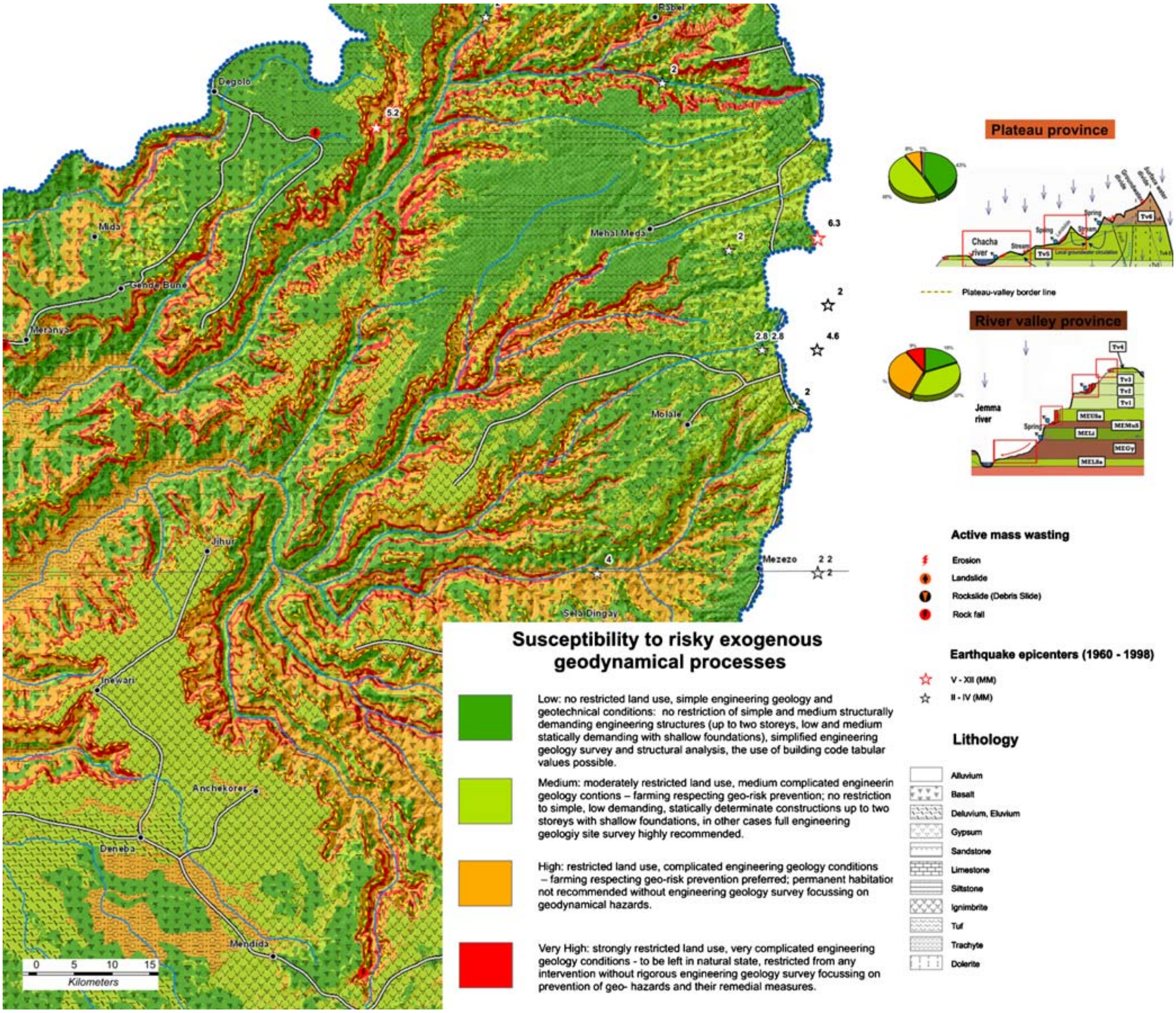

Fig. 5 Highlights of the dynamic map of vulnerability to mass wasting in Jemma River basin, at a scale of 1:250,000. Explanations: *1–4* susceptibility to risk: *1* low (no restricted land use, simple engineering geological and geotechnical conditions, no restriction to simple and medium structurally demanding engineering structures), *2* medium (moderately restricted land use, medium complicated engineering geological conditions: farming with respect to geo-risk prevention, no restriction to simple, low demanding, statically determinate constructions up to two stories with shallow foundations in the other cases full engineering geological investigation of site), *3* high (restricted land use, complicated engineering geological conditions: preference to farming with respect to geo-risk prevention, permanent habitation not recommended without an engineering geological survey focused on geo-hazards), *4* very high (strongly restricted land use, very complicated engineering geological conditions: to be left in natural state, restricted from any intervention without detailed engineering geological survey focused at prevention of geo-hazards and their remedial measures). *5–8* Active mass wasting: *5* erosion, *6* landslide, *7* rockslide/debris slide, *8* rock fall. *9* to *10* Earthquake epicenters (1960–1998): *9* V-XII MM, *10* II-IV MM. *11–20* Geology: *11* to *12* quaternary (*11* alluvium, *12* deluvium/eluvium), *13–17* Tertiary (*13* basalt, *14* trachyte, *15* ignimbrite, *16* tuff, *17* dolerite), *18–21* Mesozoic (*18* sandstone, *19* limestone, *20* gypsum, *21* siltstone)

systems theory, CHANS are able to handle characteristic attributes of coupled human nature systems characterized as the nesting of local systems in regional and global systems, the differential coupling of human and natural systems at each scale, the embedding of smaller scale processes in larger-scale ones, and the influence of larger-scale processes on the smaller-scale ones. It should also integrate methods at multiple scales and continually evaluate how small-scale phenomena are embedded in broad-scale processes and how broad-scale phenomena emerge from and influence the small-scale structure and function of CHANS. Understanding even the most local human–nature interactions requires "progressive contextualization" in which local actions are understood in terms of landscape, regional, and national factors, which in turn depend on global forces (Dietz and Rosa 2002). Therefore, the vulnerability of a community to natural hazards depends not only on local topography and subsistence activities but also on the state of regional economy, the ability of relief to reach distressed localities, and ultimately climatic global changes. Complex, highly interactive systems are also specific by inherent limitations of their predictability (e.g., Zvelebil et al. 2006). This fact dictates that nonlinearity with emerging surprises and ever-existing uncertainty should be incorporated into scenario building (Peterson et al. 2003) and decision making (Berkes et al. 2003; Morgan and Henrion 1990; Kinzing et al. 2003).

The items outlined within the discussion above provide general directions for the future aims of the project reported and for a wide-ranging interdisciplinary needed for those aims. As a starting point, geomorphology with its complex systems and geo-ecological aspect (e.g., Phillips 1999) and theory of graphs (Zvelebil 2009) have to be implemented. Emphasis should be also given to user-oriented communication and to building of geo-risk warning and management systems based on a down-up, community, and contextual approach (Zvelebil et al. 2008, 2006, 2005).

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References

Berkes F, Cokling J, Folke C (2003) Navigating social–economical systems: building resilience for complexity and change. Cambridge University Press, Cambridge, p 393

Dietz T, Rossa EA (2002) Human dimensions of global environmental change. In: Dunlap ER, Michelson W (eds) Handbook of environmental sociology. Greenwood, Westport, pp 370–406

Freeman P, Martin L, Mechler R, Warner K (2003) A Methodology for Incorporating Natural Catastrophes into Macroeconomic Projections. In: van der Veen AA, Arellano V, Nordvik JP 2003. Proceedings: Point NEDIES and University of Twente Workshop - In search of a common methodology for damage estimation. Report EUR 20997 EN (2003), Bruxelles, Office for Official Publications of the European Communities, European Union p 51–165

Kinzing AP, Starrett D, Arrow K, Bolin B, Dasgupta P, Ehrlich P, Folke C Haneman M et al (2003) Coping with uncertainty: a call for a new science-policy forum. Ambio 32:330–335

Liu JG, Dietz T, Carpenter SR et al (2007) Complexity of coupled human and natural systems. Science 317:1513–1516

Morgan GM, Henrion M (1990) Uncertainty: A guide to dealing with uncertainty in quantitative risk and police analysis. Cambridge University Press, Cambridge, 344 pp

Peterson GD, Cumming G, Carpenter S (2003) Scenario planning: a tool for a conservation in an urcertain word. Conserv Biol 17:358–367

Phillips JD (1999) Earth surface systems, complexity, order and chaos. Blackwell, Oxford

Šíma J, Zvelebil J, Krupička J et al (2009) Water resources management and environmental protection studies of the Jemma River basin for improved food security. Czech Republic Development Cooperation, Aquatest a.s., Ministry of the Environment of Czech Republic, Prague, p 224

Zvelebil J (2009) Complex systems education for natural hazard management and from down-to-up pushing of government and officials: a case study. Annales Geophysicae 16, Supp. IV.NP1.1082

Zvelebil J, Vařilová Z, Paluš M (2005) Tools for rock fall risk integrated management in sandstone landscape of the Bohemian Switzerland National Park, Czech Republic. In: Sassa K, Fukuoka H, Wang F, Wang G (eds) Landslides. Risk analysis and sustainable disaster management, chap. 14. Springer, New York, pp 119–126

Zvelebil J, Paluš M, Novotná D (2006) Nonlinear science issues in the dynamics of unstable rock slopes: New tools for rock fall risk assessment and early warning. In: Cello G, Malamud B (eds) Fractal analysis for natural hazards, chapter 6. Geological Society Special publication no. 261. Geological Society, London, pp 79–93

Zvelebil J, Nechyba M, Paluš M (2008) Automated monitoring and forecasting of rock fall danger in space and time: practical field experience. Geophys Res Abstr 10, 04352. ISSN 10297006

J. Zvelebil (✉)
Prague Department of Physical Geography and Geoecology, Faculty of Science, Geo-Tools, Zdiby, and Charles University,
Albertov St. 6,
128 43 Prague 2, Czech Republic
e-mail: zvelebilj@seznam.cz

J. Šíma
AQUATEST, a.s.,
Geologická,
152 00 Prague 5, Czech Republic
e-mail: sima@aquatest.cz

V. Vilímek
Department of Physical Geography and Geoecology, Faculty of Science, Charles University,
Albertov St. 6,
128 43 Prague 2, Czech Republic
e-mail: vilimek@natur.cuni.cz