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Landslide field research and capacity building through international collaboration

Abstract The Charles University in Prague, Czech Republic was selected as one of World Centres of Excellence on Landslide Risk Reduction for the period of 2008-2011. It focused mainly on field research and capacity building, is based on multilateral cooperation both at the national and international levels. Landslides are studied in a holistic context of the whole landscape evolution to understand the complex network of interactions between all of the relevant geomorphologic processes. The field research is carried on field mapping, direct monitoring and data analyses in several parts of Central Europe, Central Asia, selected parts of the Andes and East Africa. We are productively implementing complex system theory (e.g. plectics, non-linear dynamics, networks theory) in more relevant description, modelling and forecasting of landslide processes. Geomorphology is also a useful tool in recognition and description of large prehistoric slope movements.

Keywords Slope movements · Natural hazards · Capacity building · High mountains · Complex systems · Network thinking

Introduction

A World Centre of Excellence on Landslide Risk Reduction (Short title: Landslide field research and capacity building through international collaboration) has been established as joined research activity of Charles University, Geo-Tools NGO and Aquatest Holding, Prague. It is hosted at Charles University in Prague (Faculty of Sciences). The Centre is underway mainly in the fields of geomorphology, engineering geology, hydrogeology and complex systems science in close cooperation with other geoscience disciplines (see also Sassa 2009). Its activity scale is intercontinental and national. Investigations have been targeted into areas with a high dynamic of landscape evolution (Fig. 1) e.g. the Peruvian Andes, the East African Rift Valley in Ethiopia and the Himalayas and the Karakoram in Asia. Beside these areas, selected regions in the Czech Republic served for testing purposes (e.g. the rockfall-prone area at the border with Germany). A dynamic network has been established between working groups of the Centre for corroboration, data flow and to start network thinking.

Natural hazards studies are essential for a better understanding of ecosystem protection and the relationship between the environment, society, and human health. In the Czech Republic, the application of geomorphological research results in assessing the present dynamics of landscape changes in Central European region of the morphostructural contact of Hercynian, Alpine and Carpathian Orogene, including natural hazards and risks (Demek et al. 2006). Recent events of extreme hazardous phenomena in the Czech Republic were: a) active morphotectonics, b) slope movements and/or landslides, c) erosion of soils and d) floods.

Objectives for the initial years are focused on landslide process analysis with regard to landscape evolution in selected regions: evaluation of mass movements in overall hazard and risk assessment, occurrence of landslides by both, the creeping and rapid geo- and climatic disasters (e.g. land cover changes, land degradation, floods, earthquakes). Implementation of advanced complex automated safety monitoring systems as a part of integrated risk assessment in selected regions. Establishing the bottom-up and network-thinking based local Disaster Management Units in those regions.

There are three basic ideas behind WCoE: 1/ humans have increasingly interacted with natural systems, resulting in the formation and development of coupled human and natural systems (CHANS). Because CHANS acts not only as the hazard-inducer but also as the hazard-recipient, they have revealed a complexity of organizational and spatial-temporal couplings (e.g. Liu et al. 2007). 2/ a pro-active approach including monitoring forecasting, and accident prevention or control is more effective then the re-active activities (e.g. Hladný 2003). 3/ Almost 96% of deaths from floods, landslides and other weather-related disasters occurred in third world countries (Freeman et al. 2003).

The World Centre of Excellence hosted nowadays at Faculty of Science, Charles University in Prague is connected with the Department of Physical Geography and Geoecology. The Charles University established in 1348 is the largest university in Czech Republic with 17 faculties and 48, 000 students. The University was classified between 200 and 300 places on the Shanghai's rankings in recent time. It has around 450 bilateral agreements and 170 international partnerships with foreign universities. Geomorphological research which is the frame of the recent landslide research is strong and based on multilateral cooperation in the Department of Physical Geography and Geoecology. The department is using the equipped modern laboratories inside the faculty and created its own laboratory for sedimentological analysis and another for dendrogeomorphology.

Geo-Tools NGO was established as an integrated multidisciplinary arrangement to elaboration, practical testing and dissemination of novel, progressive methods which are emerging at intersection of complex systems theory, computing mechanics and information technologies with geodynamics. Monitoring and modelling of geodynamic processes are especially stressed. Besides theoretical work, there is a development and design department within the Geo-Tools. Its realization of an integrated monitoring system to rock fall management, which includes original, innovative hardware and firmware together with novel methods of monitoring time series evaluation (Zvelebil et al. submitted), has been awarded the Excellent Project by the Research and Development Council of Czech Republic last year.

Fig. 1 An intensive erosion and landslides on slopes of Cordillera Blanca in Callejon de Huaylas (close to Huarás in Peru). These forms of land degradation are typical results of processes after intensive rains (Photo by V. Vilímek)

Aquatest Holding provides consultancy and engineering in the fields of environment protection and water management including remedial action on contaminated sites, EIA (Environmental Impact Assessment), environmental risk analyses to large multinational corporations and state agencies in more than 20 countries. Noteworthy in this section of activities are participation in the whole state environmental auditing program of the Czech Railways and in the environmental impact assessment project of a nuclear plant in Slovakia. In the field of groundwater resources management and modernization of the state monitoring network, the company provided services mainly for the Czech Ministry of Environment. It also consults in preparation of Czech and European Union environmental legislation, and to International Development Program of Czech Republic.

Methods

The objectives of the WCoE will be attained using the following methods: A/ integrating assessment by increasing interdisciplinarity through the networking of experts and institutions in the Czech Republic and abroad (e.g. Viles et al. 2007). Several Czech as well as foreign Ph.D. students have been integrated into the research (e.g. Caceres 2007; Klimeš 2008; Klimeš et al. 2009; Hartvich et al. 2008; Vařilová and Přikryl 2008); B/ a holistic approach by implementation and creative improvement of novel scientific tools, especially those provided by the Complex Systems Theory, Nonlinear Dynamics and the Theory of Graphs (Zvelebil et al. 2008a, b, c); C/ information dissemination and capacity building in third world countries, currently Peru and Ethiopia.

The application of mathematical physical approaches and exact methods with specialized techniques and instruments for determining, describing and measuring components of the natural environment stimulates the interpretation passage from analytical research to creation of models and to the synthesis of global changes and natural systems dynamics (Kalvoda 2001; Zvelebil et al. submitted). Changes in quantitative geography, within the past decade, do not necessarily represent the development of new techniques but reflect methodological changes, e.g. how these methods are approached and results interpreted (Spurná 2008; Zvelebil 2009). Geomorphological research and other physical geographical and geo-ecological activities of this orientation contribute to knowledge of the dynamics of changes of natural systems. One example of utilization of this research work is the diagnostics of natural hazards and risks including prognosis and prediction of catastrophic events and phenomena such as landslides and related slope movements (e.g. Goudie and Kalvoda 2007; Zvelebil et al. 2008a, b, c).

Many data can be acquired from complex assessment of different kinds of satellite imageries – from DTM to geology and land cover assessment. In the first approach, idea-based models can be derived from the basic principles and general knowledge of geomorphology and engineering geology. They can be used to assess the resistance of the geological environment to mass wasting activity by grouping units according to their geomechanical and geomorphologic strengths. Perturbance and stressors as process-driving forces could be indirectly expressed by evaluation and classifying of relief energy which, under quasi-homogeneous climatic influences, becomes the main driving force of relief modelling by exogenous geodynamic processes, including the processes of mass wasting and transport of destruction products (landslides, erosion) on the one hand, and the mode of sedimentation and the quality of deposited soils on the other. The common GIS environment can serve as a data base and its integrating components, in which individual thematic information layers were analyzed, merged, and classified. This approach was tested especially during an environmental study of the Jemma River Basin in Ethiopia.

Results

Peru

Research work performed in Peru was oriented towards case studies (addressing both cultural and natural heritage sites) with the primary objectives being disaster risk assessment and monitoring (e.g. Vilímek et al. 2007). Other work associated with the analysis of databases and statistical field work on the perception of natural hazards was also carried out (Fig. 2). The area of scientific interest is Machu Picchu where cooperation through an IPL project (IPL C 101-1) as well as cooperation with

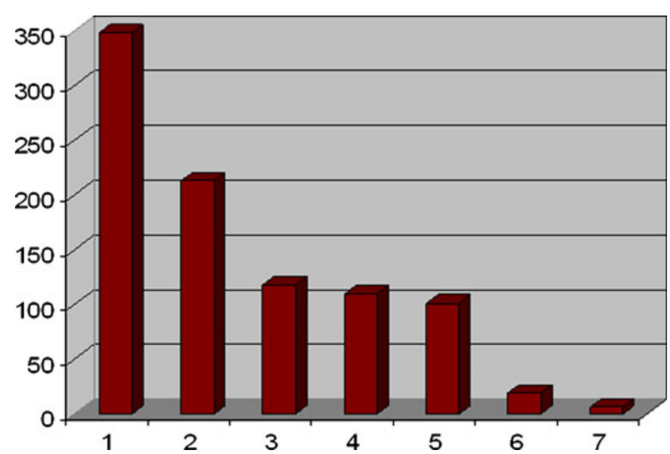

Fig. 2 Number of events of natural hazards in the Ancash Department (Peru) in the period 1971-2000 (Data by DesInventar). Explanation: 1. Landslides (348 events; 38 %); 2. floods (213 events); 3. earthquakes (118 events); 4. extreme meteorological events (110); 5. extreme precipitation (101); sea surge (19 events); forest fires (6 events)

Fig. 3 Tectonically, by peripheral, downthrow faults predisposed step-slip landscape, which are remodeled by intensive erosion and huge landslides. Besides areas of contemporary high activity, there is difficult to distinguish the relative roles of morphotectonic and climate-morphogenetic processes of relief-building (Photo by J. Zvelebil)

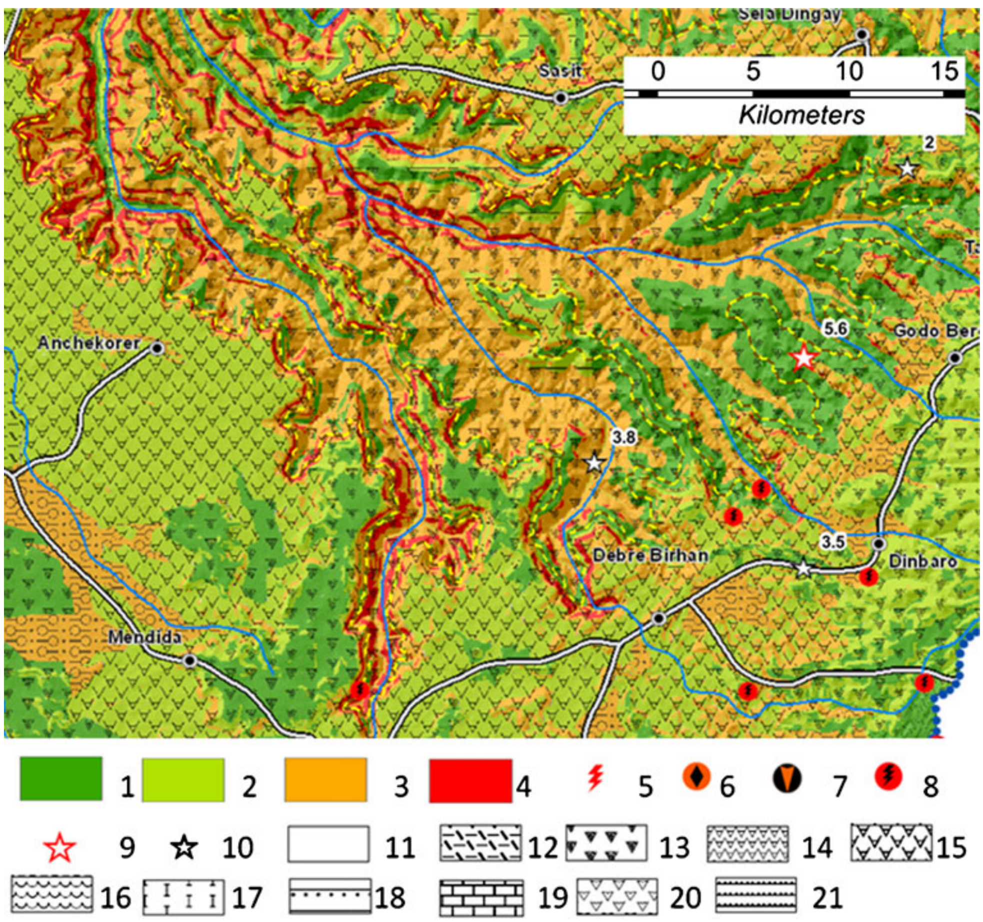

Fig. 4 Highlights from the Map of susceptibility to exogenous risky geodynamic processes, 1:200 000. Explanation: 1-4 Susceptibility to Risk: 1- Low: no restricted land use, simple engineering geological and geotechnical conditions, no restriction of simple and medium structurally demanding engineering 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 storeys 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 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; 9-10 Earthquake epicentres (1960-1998): 9 – V-XII MM; 10 – II-IV MM; 11-20 Geology: 11-12 Quaternary: 11 – Alluvium; 12 – Deluvium, Eluvium; 13-17 Tertiary: 13 – basalt; 14 – trachyte; 15 – Ignimbrite; 16 – Tuf; 17 – Dolerite; 18-21 Mesozoic: 18 – Sandstone; 19 – Limestone; 20 – Gypsum; 21 – Siltstone

other WCoEs could be documented. Besides the ongoing dilatometric and extenzometric measurements and debris flow research (Vilímek et al. 2005, 2006) other fieldwork started in 2008 dealing with infiltration regarding shallow landslides.

The advantage of landslide research in Cordillera Blanca is that the large variety of landforms and associated recent dynamic morphological processes with the coupling of different impacts yields interesting scientific tasks. For instance, rather strong deglaciation of high mountain areas together with neotectonic activity enhance landslide susceptibility and moreover the increasing population growth escalates the vulnerability of the local communities. Another interesting task is a comparison of the influences of precipitation during the El Niño phenomena and "ordinary" rainy seasons.

The statistical field works revealed one important fact that local people are not aware of the hazards of the slow but continuous progress (e.g. soil degradation) even if they are strongly dependent on agricultural production and are in day to day contact with their fields. On the other hand they some of them are afraid of the volcanic activity that finished in this region in the Tertiary age. Another case study of a recent landslide (April 2009) in Cordillera Negra stressed the fact that after 35 years the general awareness of the inhabitants has decreased (comp. also Vilímek 2003).

To understand the importance of slope movements among a variety of natural hazards it is important to understand interconnections between individual natural processes in the cause/consequence sense, when the primary might be hydrometeorological events or earthquakes and landslides are "only" consequences. However, analysis of different types of natural hazards in the Ancash (Northern part of Peru) revealed that the most frequent type of hazard was in fact landslides.

The Jemma River Basin, Ethiopia

A pilot study in the development and practical testing of suitable methodology, information dissemination and practical training of Ethiopian staff in environmental protection studies including landslide vulnerability and water resources management to improve food security in the Jemma River Basin has been accomplished in 2009 (Šíma et al. 2009). This study dealt with the assessment of hydrogeological, engineering geological and land use characteristics and other environmental parameters acquired during the office based and field work and discussion between stakeholders and the joint Czech-Ethiopian team of professionals. The project was funded by the Czech Republic Development Cooperation.

The study area was located in the central highlands of Ethiopia and at the western margin of the main Ethiopian rift. It suffers from increasing land degradation which has arisen due to land cover changes caused by rapidly increasing population pressure, whilst the population, infrastructure and settlements are endangered by mass wasting and active seismo-tectonic processes due to the geomorphologically young, high-energy relief of deep erosion dissection of the plateau, and by the activity of seismic-tectonic and seismic-gravitational processes at the rim of the Rift Valley (Fig. 3). Engineering geological and hydrogeological maps and zoning of vulnerability to mass wasting 1: 250 000 (16 000 km^2) has been carried out as a fundamental part of the project (Fig. 4).

As is common for regional studies in third world countries, the project suffered from tight time-money-technique conditions. A relative lack of direct data obtained through field mapping afforded no opportunity to a) regularly record statistics of active risk processes, b) elaborate regular data-based models for susceptibility zoning – i.e. to identify important factors in the processes studied and c) assign them different degrees to match their regional importance. Therefore, an alternative method by energy-process-oriented elaboration of engineering geological and vulnerability zoning maps was realised.

Present-day activity of mass wasting documented in the field was compared with locations of its occurrence within individual zones of different vulnerability to assess the regional authenticity of the idea-based susceptibility zoning. There has been a good conformity in the actual occurrences of events and zoning of rockfall (75 %) and landslide (83.3 %) vulnerability.

The engineering geology, hydrogeological, and vulnerability maps compiled provide baseline data for geoscientists, stakeholders and investors, as well as the community, to facilitate sustainable land use with special regard to the purposes of civil engineering, urbanism as well as for remedial projects at individual sites.

Selected regions of the Himalaya and the Karakoram

Research on the geological structure and the landforms of the Himalaya and the Karakoram has identified the extreme intensity of the geodynamic processes which, especially during the Quaternary, remodelled these mountains to their present-day shape. Geomorphological analysis of landform patterns in the Makalu – Barun region of the Nepal Himalaya, the Hispar Mustagh Karakoram (Fig. 5) and other selected areas of the High Asian mountains illustrates their relation to morphotectonic and climate-morphogenetic features of relief-building processes (Kalvoda 1992). High-mountain landforms in the Himalaya and the Karakoram are the result of morphotectonic processes, as well

Fig. 5 Lower part of the Hispar valley (western Karakoram) in the seasonally cold/warm semiarid zone is filled by a complex of slope, glacigenous and fluvioglacial deposits of Upper Pleistocene to recent ages, reaching thickness of over 200 m. Ridges above the Hispar valley are formed on the Upper Paleozoic gneisses and micaschists. The violent destruction of the alpine-type relief by climate-morphogenetic processes has been stimulated by orogenetic activity during the late Cenozoic. The rapid slope movements, including large-scale landslides in the Nagar village area with the system of terraced agricultural fields, originated on very steep denudational slopes (30–50°), which consists of Cretaceous limestones, marbles and phyllites. (Photo by J. Kalvoda)

as the denudation and erosional efficiency in different palaeoclimatic conditions during the late Cainozoic (Kalvoda 2007a).

The very high rates of glacial denudation of mountain massifs, rapid slope movements and erosive incision of canyon-like valleys also stimulate uplifts by isostatic compensation. This geodynamic process is one of the factors influencing the orogenetic uplift of Mount Everest, K 2 and other very high massifs in the Himalaya and the Karakoram during the Quaternary. Dynamic changes of landscape pattern are important evidence of the present-day severe natural hazards and risks (Kalvoda and Rosenfeld 1998; Kalvoda 2007b).

Research of landform patterns of peculiar relief types suggests extremely high rates of recent denudation, sediment transfer and deposition (Goudie and Kalvoda 2004; Kalvoda and Goudie 2007). Recent climate-driven morphogenetic processes in the extremely dissected relief with an elevational gradient of over 7 000 m are very active in the framework of extraglacial and glacial zones, the periglacial zone and the seasonally cold/warm humid and/or semiarid zones. The geomorphological observations suggest that the frequency and magnitude of recent landform changes are increasing from a very cold and dry extraglacial zone across a large periglacial area up to subtropical landscape with humid climatic conditions.

Discussion and conclusions

Disasters have to be considered as complex phenomena of multicausal origin occurring within the complex frame of the Earth's system. They may have a chain-like form of successive occurrence of individual disastrous phenomena (e.g. heavy storm, flood, landslides, agricultural disaster, some disease epidemic, social disorder). Moreover, increasing nature – human/technical interaction within globally connected human activities have brought another aspect – the aspect of coupled human and natural systems.

Due to common time-money insufficiency for field work and the multi-scale nature of landslide susceptibility and risk studies, the currently prevailing ground checking should be supported and potentially substituted by new methods of data acquisition and assessment with special attention to ever increasing types of satellite imagery and techniques for their exploitation.

The present technological level enables very high quality of collection, archiving and processing of data from field monitoring and measurements, as well as from laboratory research. The geographical aspect of the compiled databases enables the preparation of algorithms for mathematical and physical modelling of observed natural processes. Nowadays, space technologies and space data represent only one part of the inputs to disaster management activities, but they have proven their capability to provide critical support in terms of being very effective remote sensing data from wide and sometimes hard-to-be-reached areas, as well as for emergency communication. However, to understand the potential of space technologies and methods, one has to be aware of the very broad range of spatial-temporal scales in which disaster events are prepared, occur and in which their complex impacts take place. The factors and processes involved in disaster events are complex and have wide spatial-temporal scales. To optimise the implementation of space technologies for natural and technological hazard evaluation it is essential to use them in synergy with ground based methods (e.g. ground data collection, observations, field based surveys/mapping and monitoring).

Disaster prevention is relatively underdeveloped in comparison with disaster response and post-disaster activities, therefore disaster prevention needs to be emphasized and strengthened. The most obvious point is the information gap between useful data providers and their end users at nearly all levels: e.g. between space data providers and scientific evaluators of disaster risks, between the scientific evaluators and civil defence users, between civil defence information and the general public. At the most general and important levels, there is a void between experts and scientists on one side, and decision makers and the general public on the other. The geographical distance is nowadays rather easy to overcome but thematic barriers are much more difficult to cross (Jungwiertová 2008; Zvelebil et al. 2008a, b, c).

Recent studies reveal the complexity of organizational, spatial, and temporal couplings of natural and human/technical systems (CHANS – see Liu et al. 2007). Both the systems are producers, as well as recipients of risk factors and processes. Coupling of those systems has evolved from direct to more indirect interactions, to reciprocal effects, emergent properties, and other complexities which take part on a broad range of spatial and temporal scales. Although those complex patterns have long been recognized, the complex patterns and processes have not been sufficiently characterized, or fully understood. Regarding ever-increasing, global-scale human activity, there is the opportunity and strong need to integrate various disciplines to address fundamental questions of CHANS in order to meet the emerging, unprecedented challenges in society.

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