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## Scientific research for landslide risk analysis and international education for mitigation and preparedness

**Abstract** Scientific activities of the World Centre of Excellence on Landslide Disaster Reduction at Charles University in Prague (2011–2014) combine field research using several techniques, capacity building, and international collaboration. Through our landslide research in Peru, Ethiopia, and at several localities inside the Czech Republic, we consider the landslide phenomena as being a part of the physical-geographical sphere where all of the interactions between the lithosphere, atmosphere, and hydrosphere must be evaluated with respect to specific on-site conditions. Slope deformations are also considered as ongoing landscape changes in time and space. In some regions (e.g., in the Cordillera Blanca, Peru), landslides were studied as they occurred. In addition to progress in research methodologies, we have created a new glacial lake outburst floods (GLOFs) database. Doctoral candidates were involved in field research and student exchanges. Field studies also involve foreign students. Aspects of our landslide research are a matter of international collaboration in the framework of the International Programme on Landslides (IPL).

**Keywords** Slope movements · Natural hazards · Capacity building · High mountain areas

### Introduction

The World Centre of Excellence on Landslide Disaster Reduction located at Charles University in Prague was established in 2011 for a period of 3 years. The primary objective was to promote research in the fields of geomorphology and engineering geology in collaboration with other geoscience disciplines both in the Czech Republic and abroad. We followed up on our first center of excellence from the period 2009–2011 (Vilímek et al. 2010) by expanding our activities and focusing in more detail on certain topics and using networks of international collaboration (e.g., Mikos 2012). In the framework of the strategy of the IPL (e.g., Sassa 2012), we based our activities on IPL projects (e.g., Vilímek et al. 2014) in addition to bilateral and multilateral collaboration with other leading research groups in landslide sciences in the Czech Republic and other countries (e.g., Klimeš and Vilímek 2011).

There are four principal tenets of the World Centre of Excellence (WCoE): (1) since natural phenomena have complex origins (Goudie and Kalvoda 1997), studies benefit from a multilateral, or interdisciplinary approach and new methodologies are welcome (e.g., Emmer and Vilímek 2013); (2) geomorphological tools, or proxies, reveal evidence of prehistoric extreme events from which we can learn about the magnitude and frequency of possible events and properly understand landscape evolution (e.g., Klimeš et al. 2009); (3) investigations focusing on the dynamics of landscape evolution are directed toward specific regions where slope movement is a significant phenomenon (Kalvoda et al. 2013); and (4) as humans have increasingly interacted with natural systems, risk zonation takes on an important role in society (Carey et al. 2012; Klimeš et al. 2014). The objectives for the WCoE were to (a) strengthen the International

Programme on Landslides (IPL) through analysis of the role of landslide processes in landscape evolution and (b) evaluate mass movement hazards and risk assessments in the context of environmental changes, including climate (Emmer et al. 2014). The Centre was also committed to creating a network of entities that contributed to landslide risk reduction.

The WCoE was hosted at the Faculty of Science, Charles University in Prague, and affiliated with the Research Team of Geomorphology and Geodynamics in the Department of Physical Geography and Geoecology. Charles University was established in 1348 and is the largest university in Czech Republic with 17 faculties and 48,000 students. It currently has around 450 bilateral agreements and 170 international partnerships with foreign universities. The university has recently been placed between 200 and 300 in the Shanghai rankings ([www.shanghairanking.com/](http://www.shanghairanking.com/)).

To fulfill the scientific objectives of the WCoE and complement on-going projects, a number of study areas were selected from around the world. Field research and landslide risk analysis were undertaken in various localities in Czech Republic (Fig. 1), Machu Picchu and the Cordillera Blanca in Peru (Fig. 2), and the Ethiopian Highlands (Fig. 3). According to planned activities, field surveys included geomorphological mapping and detailed profiling for risk zoning.

### Research in Bohemian massive and Carpathian Mountains, Czech Republic

Interdisciplinary collaboration has a long tradition at the Department of Physical Geography and Geoecology, and is at the core of the recent landslide research, for example, collaboration with the Institute of Structure and Mechanics (Academy of Sciences of the Czech Republic). The department utilizes the modern laboratories of the faculty and has created its own laboratories for sedimentological analysis and dendrogeomorphology.

The eastern Czech Republic is the region most affected by landslides and has the greatest potential for slope processes (Fig. 1a). Here, the mountains are composed of folded and faulted flysch layers comprising alternating sandstone, conglomerate, and claystone. This geological control, together with large vertical relief differences and steep slopes, provides suitable conditions for landslides. In 2010, a combination of persistent convective-type rainfall and local storms caused daily rainfall amounts to be 30 times higher than the long-term daily average and 3 times higher than the long-term monthly average in the Czech Republic (Fig. 1b). This considerable amount of rainfall caused extreme flooding and resulted in damage to property and infrastructure, in addition to triggering landslides and changes in river channels. Rapid and shallow mass movements triggered by extreme rainfall in the Javorníky Mts. (Lemešná Mt.) were chosen for research (Fig. 1c). Detailed geomorphological mapping and monitoring of precipitation, soil moisture, and soil movement were undertaken at the

study site, beginning in 2011. The Jizerské hory Mts. (Smědavská hora Mt.) in the northern part of the Bohemian massive were another area of interest where three torrential debris flows originated. Here, detailed mapping was performed and rainfall pattern thresholds were calculated (Smolíková et al. 2015) based on detailed rainfall data available from the rainfall gauges of the Czech Hydrometeorological Institute (Fig. 1d), empirical modelling in FlowR programme was carried out as well (Blahut et al. 2012). Spatial and temporal variations of mass movement dynamics and rainfall thresholds were also examined in another area of shallow landslides along the front of a large open pit mine in the foothills of the Krušné hory Mts. (Burda 2011). Dendrogeomorphology techniques were applied to this site as powerful tools for dating events. In addition, the use of *Betula pendula* and induced changes of vessel shape were innovative methods developed for this study (Tumajer and Burda 2013).

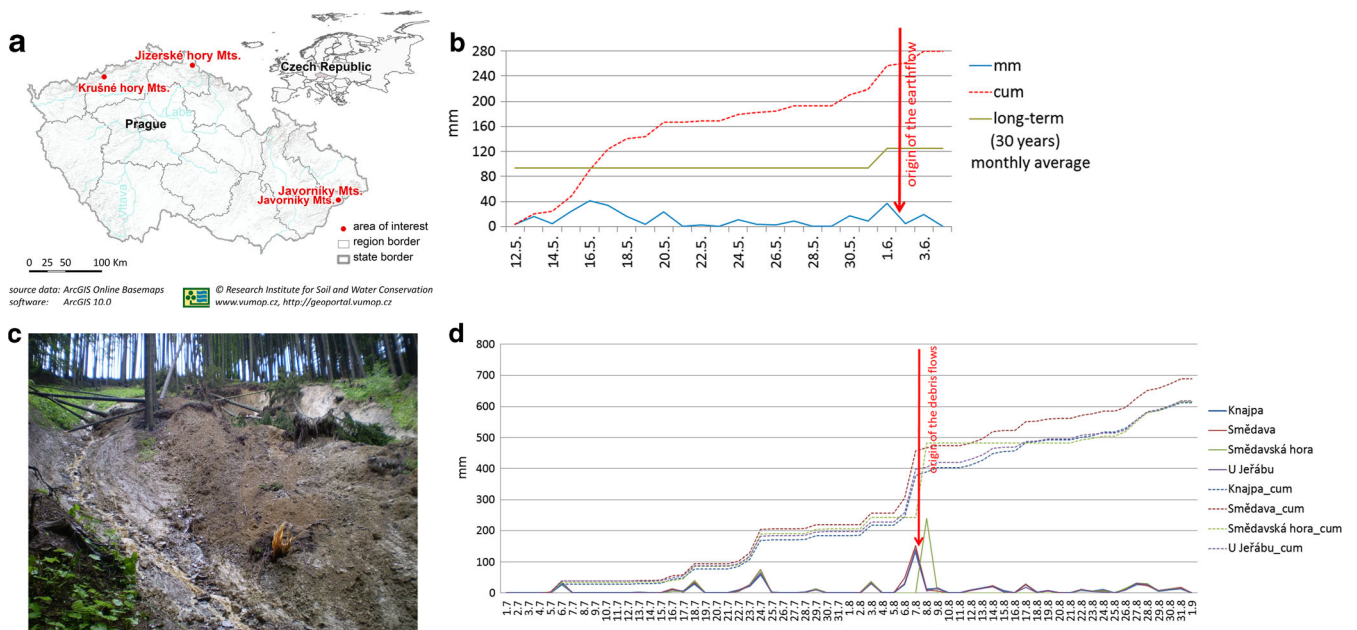
**Research in the Peruvian Andes**

In Peru (Fig. 2a), dilatometric monitoring of landslides at Machu Picchu was established in 2000 (Fig. 2b) and has been performed continuously since 2002 (Vilímek et al. 2005). More recent studies are connected with glacial lake outburst floods (GLOFs), where research work focuses on developing appropriate methods for hazard evaluation in the Cordillera Blanca (Emmer and Vilímek 2014). Monitoring of slope movements is a powerful tool for quantifying recent morphological changes. For example, landscape changes can be detected by comparing photographic and satellite imagery time series. Remote sensing data were used for landslides and glacial lakes inventories in high mountain areas of the Andes (e.g. Huascarán National Park). Moisture and temperatures were monitored inside moraines in the Cordillera Blanca mountain range.

GLOFs are complex phenomena, with several triggers directly connected with slope movements (e.g., landslides in moraines, ice or rock falls). Lake outbursts and dam overflows also usually result in debris flows. Regionally specific triggering factors were revealed for the Cordillera Blanca (Emmer and Vilímek 2014). Geomorphological mapping based on field mapping remote sensing data around Lake Palcacocha reveals moraine instability processes and the degradation of the Jatunraju glacier. Modeling and hazard zoning were performed as a case study in the Chucchún catchment after a significant GLOF (Klimeš et al. 2014). Maintaining the worldwide database of GLOFs in the framework of IPL project No. 179 is one of our contributions to the global IPL strategy (<http://iplhq.org/category/iplhq/ipl-ongoing-project/>), (Vilímek et al. 2014).

**Research in the Ethiopian Highlands**

Specific methodologies were developed in order to fulfill landslide research objectives in the Ethiopian Highlands (Fig. 3a): an area of recent tectonic activity with a highly dynamic relief evolution history in the young Cenozoic (Kalvoda et al. 2010, 2013). To detect landscape changes, geomorphological mapping incorporated field work with time series analysis of remote sensing data and photos in remote areas. The Global Gravitational Model EGM 2008 was tested at scales from 1:500,000 to 1:3,000,000 to re-create the geomorphology and geodynamics of the Ethiopian Highlands. Rates of recent geomorphic processes were then compared to the calculated anomaly of selected parameters of EGM 2008. Type localities were selected for case studies where detailed landslide activity research was previously undertaken, e.g., Dessie graben (Vařilová et al., in print, 2015).



**Fig. 1** a Location map showing study sites in the Czech Republic. b Rainfall record in 2010 in the Javorníky Mts. c Earthflow in Lemešná in the Javorníky Mts. (photo by J. Kaděřka). d Rainfall record in 2010 in the Jizerské hory Mts

In the Jemma River basin, geomorphological processes responsible for the evolution of slopes in a canyon-like valley (Fig 3b) and the connections between landslide typology and sediment flux are under investigation. The landslide inventory was derived from remote sensing data and a new automatic methodology for lineament drawing. The variability of the morphometric characteristics of valley networks was studied by Křížek and Kusák (2014). Remote sensing techniques for the analysis of valley network development through land degradation processes (e.g., landslides, erosion) were developed through collaboration with the University of Tuebingen, Germany. Valley networks in the Ethiopian Highlands were defined and compared: (1) in basic terms of fractal geometry, i.e., the fractal dimension, self-similar, self-affined and random fractals, hierarchical scale, fractal self-similarity, and the physical limits of a system and (2) by selected methods of estimating the fractal dimension of drainage patterns and valley networks (Kusák 2014). To evaluate the hierarchical scale and fractal self-similarity of fractal landscape shapes forming complex networks (i.e., drainage patterns and valley networks), suitable morphometric characteristics have to be used and a suitable scale was selected in order to evaluate in a representative and objective manner (Křížek and Kusák 2014). In this way, over 400 landslides were remotely mapped and divided into the appropriate categories. A limiting factor was the quality of satellite images covering the area, which varied greatly in places and complicated the mapping. The inventory of mass movement processes in Debre Libanos (Fig. 3c), derived using remote sensing techniques, was subsequently verified in the field. The total number of landslides increased after the fieldwork.

Next, the morphological characteristics will be applied to the digital model of valley networks in the area of the Ethiopian Highlands adjacent to the Rift Valley (Fig. 3a). The objective here is to determine the relationship between the morphological type of valley network and the frequency, length, and azimuth of lineaments. Through this work, changes in the values of morphological characteristics of valley networks depending on the landscape development will be revealed.

In 2014, a project entitled “Taza Sustainable Livelihood Development in Southern Nations Nationalities and Peoples Region in Ethiopia” was launched in collaboration with a NGO Caritas Czech Republic and the Research Institute for Soil and Water Conservation in Prague. This project aims to ensure sustainable sources of livelihood for the rural population in the Woreda of Kedida Gamela close to Durame, specifically on four areas of interest of 5 ha each one (Karchicho, Fig. 3d), and addresses soil erosion, slope deformation protection, and erosion control measures.

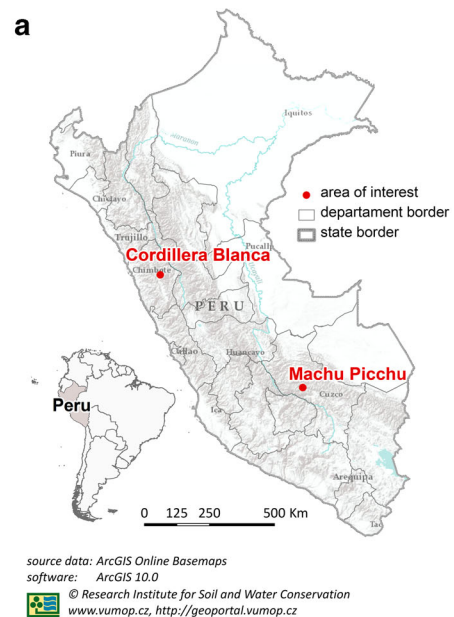
### Capacity building

Capacity building, teaching, and implementation of advanced technologies are indivisible activities in the framework of the WCoE. PhD students have been incorporated into our research teams operating in Peru and Ethiopia. Most students are affiliated to Charles University in Prague, although exchanges with universities in Tuebingen (Germany) and Firenze (Italy) are ongoing.

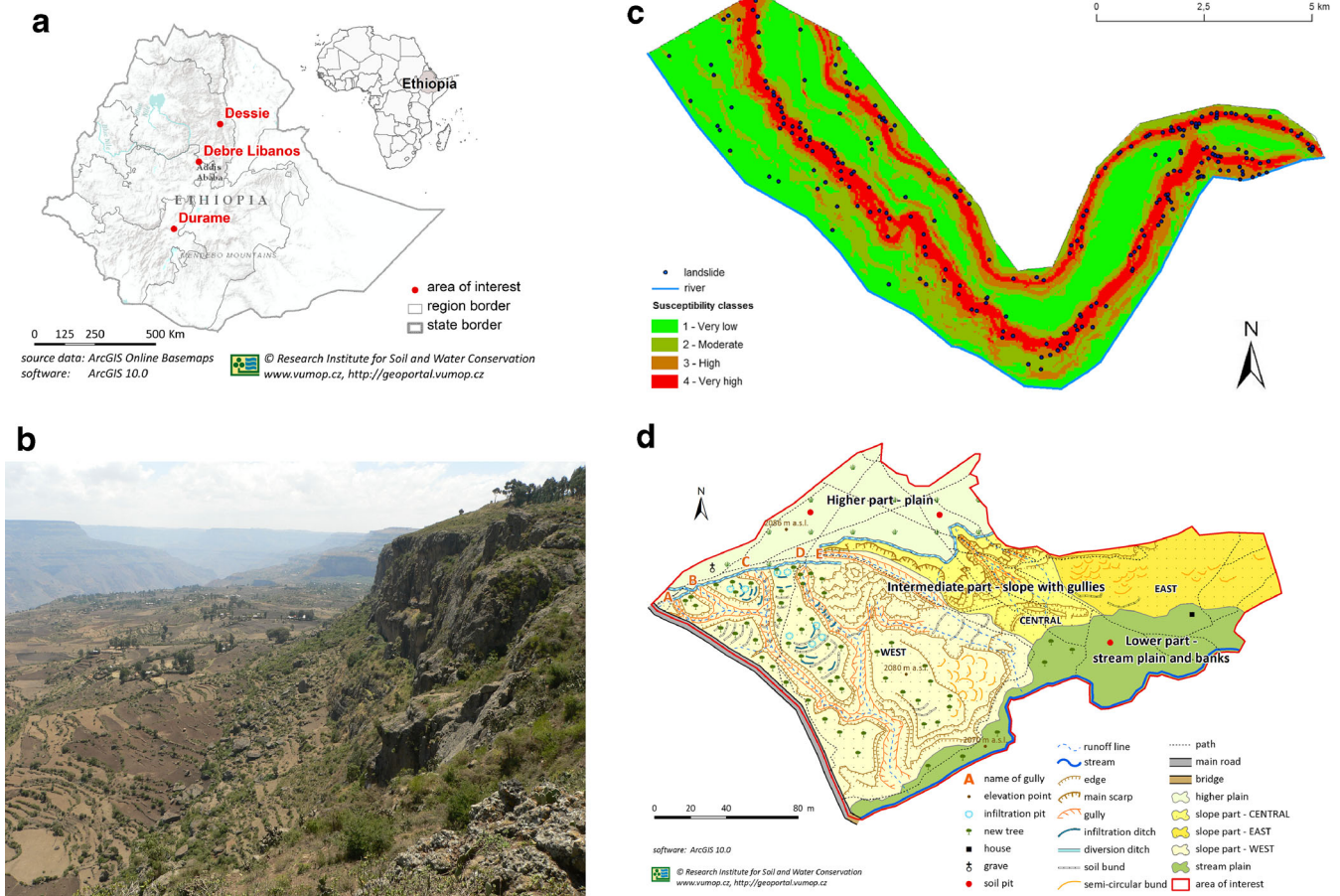
Collaboration with Peruvian students extends to training and the use of our field equipment (e.g., a portable ERT). The main aim of capacity building and teaching activities is to make available new research opportunities for European students (e.g., Emmer and Cochachin 2013) and strengthen collaboration between European universities. Scientific collaboration with Peruvian and Ethiopian students could be extended beyond the recent work of Caceres (2007).

### International collaboration

International collaboration goes hand-in-hand with not only the foreign student exchange program, but also other activities. The IPL activity to create different networks resulted in closer collaboration between research and university institutions. Some bilateral and multilateral contacts have already produced important



**Fig. 2** a Location map showing study sites in the Peruvian Andes. b Study sites with dilatometric monitoring at Machu Picchu (Peru)



**Fig. 3** a Location of the Ethiopian Highland. b The slopes of deep canyons in the catchment of the Jemma River are prone to several slope movements, especially rock falls in the upper part and landslides in lower parts (photo by V. Vilímek). c An example of landslide susceptibility map of Berisha River (after Maca 2015). d The map of erosion of Karchicho study area in Kedida Gamela

tools for strengthening landslide hazard and risk mitigation and preparedness. In the framework of the ICL Network for Landslides in Cold Regions, the WCoE has contributed to the publication of a book by the chapter (Emmer et al. 2014). Collaboration has also been established inside the ICL Thematic Network for Landslide Monitoring and Warning (Mikos 2012). And lastly, long-term research interests in the Peruvian Andes could be significant contributions to the ICL Latin-American Network (Alcantara-Ayala and Oliver-Smith 2014).

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