Mudflow and landslide hazards under climate change

– lessons from the Emilia Romagna 2023 disaster (Italy)

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Mudflow and landslide hazards under climate change
- lessons from the Emilia Romagna 2023 disaster (Italy)

TABLE OF CONTENTS

PROGRAMME

19:00 | ICEBREAKER

9:00 - 10:00 | BREAKFAST

10:00 - 11:30 | SESSION 1

Opening remarks

Assessment of hydro-erosive processes in the Vernazza catchment, Liguria, Italy
Michael Märker, Ivano Rellini, Elmar Schmaltz

New tool for detecting active landslide slopes as a basis for spatial planning in mountain areas
Ireneusz Malik, Małgorzata Wistuba

Assessment of sediment dynamics in the Vernazza Basin using a quantitative modelling approach, Liguria, Italy
Priscilla Niyokwiringawa

Tree rings as an early warning against catastrophic landslides: assessing the potential of dendrochronology for determining slope stability (examples from Poland and Italy)
Małgorzata Wistuba, Ireneusz Malik

Integrated GIS-based modelling procedure for supporting sediment-related hazard mapping in Mediterranean landscapes
Manuel La Licata, Michael Märker

Discussion

11:30 - 11:45 | BREAK

11:45 - 13:15 | SESSION 2

Landscape and paleoenvironmental reconstruction of the Sarno River Plain: Findings from the SALVE research project
Michael Märker

Catastrophic landslide events in the Polish Carpathians - causes, effects and recognition
Elżbieta Gorczyca

Geophysical investigations at the Alta Val d'Aveto area characterized by a glacial history
Patrizio Torrese

PROGRAMME

Can low-magnitude earthquakes act as a triggering factor for landslide activity? Examples from the Western Carpathian Mts, Poland
Małgorzata Wistuba

Analysing the effects of the biochar on soil properties
Azadeh Katebikord, Michael Märker

Discussion

13:15 - 14:45 | LUNCH *(not included)*

14:45 - 18:45 | SESSION 3

Dendrogeomorphological evidence of biomechanical weathering caused by tree roots
Ireneusz Malik, Łukasz Pawlik, Małgorzata Wistuba, Albert Ślęzak

Workshop "Research methods for environmental hazards"

19:00 | DINNER

Friday, 8.11.2024

9:00 - 10:00 | BREAKFAST

10:00 - 11:30 | SESSION 4

Predicting dust emission hotspots in southwestern Buenos Aires province using MaxEnt and satellite data
Juan M. Casañas, Pablo M. Cometto, Michael Märker

Mass movements of differing magnitude and frequency in a developing high-mountain area of the Moxi basin, Hengduan Mts, China – A hazard assessment
Ireneusz Malik, Małgorzata Wistuba, Yongbo Tie, Piotr Owczarek

Wind erosion assessment in the Awash Basin, Ethiopia, using Open-Source Access in Google Earth Engine
Mohammedawel Jeneto, Azadeh Katebikord, Roger Funk, Michael Märker

Discussion on future cooperation

Closing remarks

Preface

Recently, numerous natural disasters have been observed, mainly caused by increasing numbers of extreme natural phenomena affecting areas with growing populations. People inhabit areas that, until recently, were uninhabited. This primarily concerns overpopulated countries such as China, where cities grow on deserts, e.g., Urumqi, which has a population of 3,000,000. Currently, issues related to progressive desertification and water supply to the city have led to depopulation. During the last two years, the population of Urumqi decreased by 1,000,000. On the other hand, cities grow in the Sino-Tibetan Mts., China, where people are endangered by disastrous earthquakes, floods, debris flows and landslides of significant magnitudes. In Europe, an increasing number of natural disasters, including floods and landslides, cause substantial material losses and endanger human lives. In 2024, solely, floods occurred not only in Poland and Italy but also in the Czech Republic, Austria, Slovenia and Romania. The floods have led to the destruction of infrastructure, including buildings and roads, and human casualties. Hazardous natural phenomena can also lead to catastrophes that would affect the whole Earth, such as Phlegrean Fields' supervolcano. It erupted 40,000 years ago and caused global weather disturbances. The eruption could also contribute to the extinction of the Neanderthal population.

More and more frequent occurrences of natural disasters make it necessary to search for new prediction methods. To develop methods for predicting natural catastrophes, using as long sets of environmental data as possible and the latest research methods is necessary. The conference "Mudflow and landslide hazards under climate change - lessons from the Emilia Romagna 2023 disaster (Italy)" organised by the Polish Academy of Sciences – Scientific Centre in Rome, with the University of Pavia, Italy and the University of Silesia in Katowice, Poland, aims for the exchange of experiences and enhancing cooperation of researchers from Poland and Italy, in particular in the field of developing new tools for predicting disastrous mass movements and floods. The conference will provide the opportunity to discuss the results of two projects funded by the Polish National Agency for Academic Exchange (NAWA) in the Urgency Grants scheme. The first project concerns research on "Mudflow and landslide hazard in changing climate – lesson from the 2023 Emilia Romagna catastrophe (Italy)", while the second focuses on "Dendrochronological record of seismic activity and related changes in terrain topography of the Phlegraean Fields supervolcano and its surroundings".

Agnieszka Stefaniak-Hrycko - Polish Academy of Sciences Scientific Center in Rome

Małgorzata Wistuba - University of Silesia in Katowice

Michael Märker - University of Pavia

Ireneusz Malik - University of Silesia in Katowice

ASSESSMENT OF HYDRO-EROSIVE PROCESSES IN THE VERNAZZA CATCHMENT, LIGURIA, ITALY

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The steep Mediterranean catchments such as the Vernazza catchment in Liguria underwent drastic socio economic changes in the last decades. Moreover, these basins are also subject to climate variability and potential future climate change effects. Agriculture on terraced slope systems is very cost and labour intensive and thus, not competitive with highly mechanised agriculture. Consequently, many surfaces changed from terraced vineyards and olive growth to abandoned land. Furthermore, tourism based on the natural and cultural heritage of the region is more and more important for the income of the inhabitants.

However, the abandonment has effects on the entire landscape system in terms of hydrological dynamics, sediment dynamics as well as soil characteristics and the terraces itself. These changes are leading to a succession in vegetation, destabilization of slope systems, and changes on the runoff and sediment discharges. This in turn is influencing disasters such as the Vernazza event on the 25.10.2011. Heavy rainfall triggered several landslides and debris flows moving large amounts of material accumulated along the stream network to the outlet of the basin covering the village of Vernazza with up to 4m of sediments. In this study we present an stochastic assessment of the landslide and debris flow susceptibility. Moreover, we calculated with a simple model the peak runoff and sediment discharges of expected extreme events.

NEW TOOL FOR DETECTING ACTIVE LANDSLIDE SLOPES AS A BASIS FOR SPATIAL PLANNING IN MOUNTAIN AREAS

Ireneusz Malik[1] , Małgorzata Wistuba[1]

[1]Faculty of Natural Sciences, Institute of Earth Sciences, University of Silesia in Katowice

Spatial planning in mountainous areas at risk of landslides is difficult due to the need to exclude areas at risk from development. The methods used so far to detect active landslides are very expensive, e.g. installing inclinometers or conducting regular laser scanning of the ground surface. Additionally, the use of these methods requires observations that start from the moment of installing the equipment or conducting research. In the case of using dendrochronology, the landslide reconstruction reaches 200-300 years, depending on the age of the stand. Only long data sequences allow for determining the landslide hazard. Recently, radar interferometry has been an exact tool for reconstruction and prediction, but the obtained results cover the period from 2014. The paper proposes the use of the tree growth eccentricity index as an indicator of landslide activity on the slope. Thanks to large-scale research, it is possible to develop landslide hazard maps for large areas using the index. The results of such work can be implemented in the local spatial development plan.

ASSESSMENT OF SEDIMENT DYNAMICS IN THE VERNAZZA BASIN USING A QUANTITATIVE MODELLING APPROACH, LIGURIA, ITALY

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To understand the dynamics and potentially affected areas in terms of source, transport, and deposition of sediments we applied the Limburg Soil Erosion Model (LISEM). LISEM is based on detailed soil, topography and landuse information. We applied the model on a 1m scale using climatic data from two nearby weather stations and detailed soil geotechnical properties collected from the field. LISEM assessed the hydrological dynamics and related processes linked to surface runoff such as soil erosion processes as well as landslides related to the soil water content.

We use the disastrous extreme rainfall event occurred on the 25th of October 2011 with numerous landslides and severe soil erosion caused fatalities and economic losses amounting to millions of Euros. Vernazza is characterized by a terraced landscape and steep slopes. Most of the terraces are abandoned and used for vine and olive production in former times which makes it more vulnerable to extreme events. The related processes are triggering each other and lead to degradation of the slopes and particularly affect abandoned terraced areas.

The results show the spatial distribution of soil erosion processes and landslides. Moreover, we characterise the sediment transport pathways and depositional zones. The results help to identify critical areas needing interventions and particularly to recognize the abandoned terraces prone to collapsing. Hence, our LISEM approach yield valuable information for basin managers, farmers and environmental protection agencies.

TREE RINGS AS AN EARLY WARNING AGAINST CATASTROPHIC LANDSLIDES: ASSESSING THE POTENTIAL OF DENDROCHRONOLOGY FOR DETERMINING SLOPE STABILITY (EXAMPLES FROM POLAND AND ITALY)

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[1]Faculty of Natural Sciences, Institute of Earth Sciences, University of Silesia in Katowice

We investigated three slopes in southern Poland, subject to catastrophic, sudden landslides. To reconstruct past landslide activity, we used a per cent index method to analyse ring eccentricity in trees growing on landslides. We obtained data on year-by-year changes in eccentricity patterns of single specimens and landslide events dated from the whole population of trees sampled on each slope. These data supplied indirect information on the temporal variability of landslide activity on the three slopes, revealing that all three slopes were subject to frequent landslide activity well before catastrophic events in 1997 and 2010. The study also showed that 3–5 years before a catastrophic event, the sample trees started to record increasing ground instability, demonstrated as an uninterrupted, sudden increase in the eccentricity of single trees. Thus, the application of dendrochronological methods can reveal slopes at an increased risk of catastrophic landsliding well in advance. The method shows great promise for forecasting catastrophic landslides, and we have subsequently applied it to assess the stability of selected landslide slopes in the Italian Apennines, including a landslide descending to the Lago di Trebecco reservoir (Piacenza, Emilia-Romagna).

INTEGRATED GIS-BASED MODELLING PROCEDURE FOR SUPPORTING SEDIMENT-RELATED HAZARD MAPPING IN MEDITERRANEAN LANDSCAPES

Manuel La Licata[1], Michael Märker [1,2]

[1] University of Pavia, Italy

[2] Leibniz Centre for Agricultural Landscape Research, Germany

Soil erosion and water storages degradation by sediment deposition threaten Mediterranean landscapes. Identifying hotspots of sediment dynamics requires combining geomorphic spatial data with structural and functional properties of sediment connectivity. The HOTSED GIS-based model has been designed to address the lack of integrated methods. Our general framework involves creating an Inventory Map of sediment sources/sinks with a corresponding database. Then, the geomorphic Potential of Sediment Sources (PSS) is estimated through a relative scoring system. Proxies for Structural Sediment Connectivity (STC) and Potential for Sediment Transport (PST) are computed by combining terrain/hydrological parameters, land use data, and rainfall erosivity. These components are then integrated through a raster-based calculation procedure. Testing the HOTSED model in the upper Val d'Arda (Northern Apennines, Italy), we detected emergent landscape properties allowing the identification of "relative hazard" classes for sediment production and delivery. Results revealed hotspots with very high hazard potential near main channels or upstream of the reservoir, as well as areas prone to store sediments in depositional landforms with low geomorphic potential and connectivity. Our results indicate that HOTSED can be used as a valuable tool supporting decision-makers towards a sustainable watershed management.

LANDSCAPE AND PALEOENVIRONMENTAL RESCONSTRUCTION OF THE SARNO RIVER PLAIN: FINDINGS FROM THE SALVE RESEARCH PROJECT

Michael Märker[1,2]

[1]Pavia University Dept. Earth and Environmental Sciences, Italy
[2]Leibniz Centre for Agricultural Landscape Research, Germany

Ancient Pompei was destroyed by the pyroclastic material deposited after the eruption of Monte Vesuvius AD 79. The archaeological site of Pompei was studied intensively for more than 265 years. However, even though Pompei itself was studied in detail, the environmental context of the hinterland of Pompei is widely unknown. To fill this research gap in 2006 the German Research Foundation (DFG) and the German Archaeological Institute (DAI) financed a project entitled: Sarno River plain – Ancient Life in the Vesuvian Environment (SALVE). In this project archaeologists and natural scientists from various German and Italian Institutions worked on the reconstruction of the cultural landscape of the Sarno River plain before the eruption of Somma Vesuvius AD 79. In the area the historical sites were buried by deposits of up to 15m thickness. We applied interdisciplinary approaches considering stratigraphic investigations, GIS based spatial analysis, soil and botanical studies. More than 2.000 stratigraphic core drillings were collected and used to establish a high-resolution digital elevation model of the topography before the AD79 event based on advanced spatial statistics. Subsequently, stratigraphic and Paleosoil information was used to reconstruct the paleoenvironment of the Sarno River Plain and to derive a conceptual Landscape evolution model for the Sarno River plain.

CATASTROPHIC LANDSLIDE EVENTS IN THE POLISH CARPATHIANS - CAUSES, EFFECTS AND RECOGNITION

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The subject of this study is the complexity and staging of the evolution of landslide slope relief and its land use in the Polish Carpathians. The evolution of landslide slopes has been presented based on a cluster of landslide events in 1997-2010. A very high landslide intensity characterizes the Carpathian Flysch Mountains. Landslides occupy from 30 to as much as 70% of the slopes. The Carpathians have a high population density (about 130 people per km2), and the slopes are characterized by low gradients, encouraging the population to settle and develop agriculture. The evolution of landslide relief occurs during extreme hydro-meteorological events. One of these was the intense rainfall in 1997. After this event, about 20,000 Carpathian landslides became active. Six areas occupied by landslides of up to 65% were selected for detailed study. These landslide slopes were activated to different degrees during the 1997 landslide event. Based on field surveys and analysis of NMT and orthophotos, the degree of activation of landslide slopes (from 8 to 26% of the area) and changes in landslide relief were recognized. Twenty years after the landslide event, changes in the use of the activated parts of the landslides were also analysed.

GEOPHYSICAL INVESTIGATIONS AT THE ALTA VAL D'AVETO AREA CHARACTERIZED BY A GLACIAL HISTORY

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[1] Università di Pavia, Italy

[2] Università di Genova, Italy

[3] Uniwersytet Śląski w Katowicach, Poland

This study presents new results from Electrical Resistivity Tomography (ERT) geophysical surveys for the investigation of the shallow subsoil at the Alta Val d'Aveto area (Liguria, North-Western Italy). This study arises from the need to provide further clues around the presence of glacial deposits, their thickness and geometry, in the area. Two ERT profiles were acquired at the study area in mid-June 2024. The longer profile, profile ERT2, is 235 m in length and was obtained using 48 electrodes spaced 5 m apart in a NNE-SSW orientation: this profile was acquired to identify the glacial deposits above the substrate, their thickness and geometry up to a depth of 34 m. The shorter profile, profile ERT1, is 94 m long and was obtained using 48 electrodes 2 m apart in a SSW-NNE orientation: this profile was acquired to provide a more detailed image inside the glacial deposits in the first 13 m of depth. Even if accurate calibration of the geophysical models is currently missing, this study revealed that the glacial deposits should have a thickness between 15 m and 25 m along the investigated profiles; furthermore, the presence of at least three stratigraphic facies has been identified; these are characterized by an alternation of sediment grain size between fine and coarse. Geophysical investigations have also revealed the presence of boulders.

CAN LOW-MAGNITUDE EARTHQUAKES ACT AS A TRIGGERING FACTOR FOR LANDSLIDE ACTIVITY? EXAMPLES FROM THE WESTERN CARPATHIAN MTS, POLAND

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There are numerous examples of the impact of strong earthquakes on landslide activity. There is, however, very little information about the ability of low-magnitude earthquakes (M<5.0) to affect the stability of pre-existing landslide slopes. Two landslides were studied (Western Carpathians, Poland), located 20-30 km from epicentres of M≤4.4 earthquakes. We have used tree rings to date past landslide movements possibly caused by earthquakes. We distinguished earthquake-triggered landsliding with no impact of precipitation, precipitation-triggered landsliding with no seismic impact and landsliding triggered by the overlapping impact of precipitation and earthquakes. The study demonstrates the ability of low-magnitude (M<5.0) earthquakes to trigger landslide activity, even at distances larger than appears from limiting curves published for co-seismic landslides. The results also suggest that the activity of the Kamień landslide can be influenced by the long-distance (over 500 km) influence of strong earthquakes (M 6.8-7.4) from outside of the study area. The role of seismic factors in triggering landslides is underestimated in the study area and other regions that are seismically non-active or have low seismic activity.

ANALYSING THE EFFECTS OF THE BIOCHAR ON SOIL PROPERTIES

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Spatial planning in mountainous areas at risk of landslides is difficult due to the need to exclude areas at risk from development. The methods used so far to detect active landslides are very expensive, e.g. installing inclinometers or conducting regular laser scanning of the ground surface. Additionally, the use of these methods requires observations that start from the moment of installing the equipment or conducting research. In the case of using dendrochronology, the landslide reconstruction reaches 200-300 years, depending on the age of the stand. Only long data sequences allow for determining the landslide hazard. Recently, radar interferometry has been an exact tool for reconstruction and prediction, but the obtained results cover the period from 2014. The paper proposes the use of the tree growth eccentricity index as an indicator of landslide activity on the slope. Thanks to large-scale research, it is possible to develop landslide hazard maps for large areas using the index. The results of such work can be implemented in the local spatial development plan.

DENDROGEOMORPHOLOGICAL EVIDENCE OF BIOMECHANICAL WEATHERING CAUSED BY TREE ROOTS

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We studied of the wood anatomy of roots of Norway spruce (Picea abies (L.) Karst) growing in fractured bedrock reveals widening of bedrock cracks. Analysis, under a transmitted-light microscope of 30 micro-sections of three roots from two trees, shows that the most common anatomical features of roots growing in fractured bedrock are the blocking of radial growth, multi-directional uneven radial growth and fan-shaped deformation of cell rows. Crack widening is indicated by a sequence of features: normal growth followed by blocking of radial growth, then reappearance of radial growth. Changes in crack shape are shown by formation of traumatic resin ducts followed by radial growth eccentricity or multidirectional uneven growth. Eccentricity and radial growth release and an abrupt decrease in cell size imply increasing space for root growth and root exposure. We found inconclusive evidence of crack widening due to pressure from increasing root size (biomechanical weathering). Nevertheless, root anatomy indicates sudden crack widening, with other possible causes including tree-trunk flexing of roots by strong winds, mass-movement or freeze-thaw processes.

PREDICTING DUST EMISSION HOTSPOTS IN SOUTHWESTERN BUENOS AIRES PROVINCE USING MAXENT AND SATELLITE DATA

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Atmospheric aerosols are crucial in biological and geophysical processes, influencing the Earth's energy balance by scattering and absorbing solar radiation. Dust storms have been associated with health issues, such as cardiopulmonary diseases, and play a role in nutrient transport. Models have been developed to assess soil erosion caused by wind and water, focusing on areas of sediment accumulation, which are prone to wind erosion. Recent research has also integrated erosion models with dust source maps to better understand dust transport. This study applied the MaxEnt model to predict dust emission sources in a closed basin in southwestern Buenos Aires, Argentina. Using satellite data, including Aerosol Optical Depth (AOD), Soil Organic Carbon (SOC), and aridity indices, the model identified potential dust emission areas. The analysis also explored the relationship between dust emissions and factors such as vegetation transpiration, land cover, and topography. Cross-validation techniques confirmed the model is accuracy, producing a detailed map highlighting regions most at risk for wind erosion. The study underscores the significance of soil organic carbon and AOD in predicting dust emissions, offering insights for better monitoring and erosion control in vulnerable areas.

MASS MOVEMENTS OF DIFFERING MAGNITUDE AND FREQUENCY IN A DEVELOPING HIGH-MOUNTAIN AREA OF THE MOXI BASIN, HENGDUAN MTS, CHINA – A HAZARD ASSESSMENT

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Assessment and management of mass-movement hazard in developing mountain areas is a significant human problem. It can only be resolved through identifying the background behind the processes, including their magnitude and frequency. However, catchment monitoring is rare and historical records are often fragmentary or absent. In such cases dendrochronology can be one of the most precise methods for dating past mass-movement events. Our study is intended to provide a tree-ring based discussion of hazards caused by mass movements in a developing high-mountain area. The goal is to estimate the frequencies and magnitudes of mass movements of differing origin and scale: large and smaller debris flows, and rockfalls, typically endangering the population of the Moxi basin (Sichan Province, China). Based on the results from three study sites representing typical mass-movement hazards, the densely inhabited main valley of the Moxi basin is affected by 40 large debris flows, hundreds of smaller debris flows and thousands of single rockfalls per century. The hazard affects as much as 27.07% of developed area of the Moxi basin. However, thanks to sustainable land use, the majority is affected by manageable, high frequency, but middle-to low-magnitude phenomena.

WIND EROSION ASSESSMENT IN THE AWASH BASIN, ETHIOPIA, USING OPEN-SOURCE ACCESS IN GOOGLE EARTH ENGINE

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Soil erosion is a significant global issue, contributing to land degradation and posing serious challenges to food security. This is especially critical in vulnerable regions such as Ethiopia, where soil erosion has widespread impacts. In the Awash River Basin, home to over 18 million people experience diverse erosion processes due to varying climate and topography. While many studies have focused on water erosion, there is a gap in research on wind erosion. This study aims to address that gap by utilizing open-source datasets from Google Earth Engine to apply the Revised Wind Erosion Model (RWEM). Thus, this study will help to better understand wind erosion dynamics in this region using accessible, open-source tools.