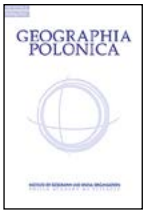

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THE IMPACT OF NATURAL AND ANTHROPOGENIC FACTORS ON THE LANDFORMS AND LANDSCAPES OF MOUNTAINS AND THEIR FORELANDS

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Abstract

This paper is an introduction to a collection of nine studies that are intended to fill the gap in the literature associated with landform development and landscape changes related to natural forces and human activities in the Central European Mountains and their close forelands. The papers are grouped into four general categories that describe the influence of climate on glacial landforms and snow avalanches, the evolution of slopes in high mountains, the development of mid-mountain relief, and changes in fluvial systems in mountains and their forelands. This paper summarises the contributions of these studies to this special issue and attempts to outline possible avenues of future research on landforms and landscapes in mountainous areas.

Key words

mountains • geomorphological processes • human impact • landforms • landscapes

Introduction

Mountains account for about one-quarter of the terrestrial surface area of the Earth (Price et al., 2013). Their landscapes, comprised of landforms, ecosystems, and anthropogenically modified land, represent long periods of geological and anthropological history (Slaymaker et al., 2009). Mountains evolved over millions of years as a result of both internal and external natural forces, while humans have affected change over only a few thousand years; however, their impact on the environment has increased significantly in the last century. In the context of this evolution, mountains exhibit a greater

Figure 1. Prof. Zofia Rączkowska in the Tatra Mountains during field work (photo courtesy of J. Cebulski)

geodiversity than many other landscapes but, equally, are also more vulnerable to a greater range of disturbances (Barsch & Caine, 1984). Depending on one's definition of a "mountain", it can be argued that about 10-20% of the world's population currently lives in the mountains, and a further 40% live adjacent to mountain areas (UNEP-WMCMC, 2002; Gardner et al., 2013). This unique combination of natural forces and the diverse human activities associated with recent population growth underlines the urgent need to better understand how these drivers of change affect mountain landforms and landscapes.

Dedication of the special issue

This special issue of Geographia Polonica is dedicated to Professor Zofia Rączkowska (Fig. 1) on the occasion of her 70th birthday. Prof. Z. Rączkowska's scientific career is strongly associated with the Department of Geomorphology and Hydrology of Mountains and Uplands (currently the Department of Geoenvironmental Research) in the Institute of Geography and Spatial Organisation of the Polish Academy of Sciences, Kraków. As the head of the department between 2010-2022, she successfully introduced and implemented the ethical principles of medicine, embodied by the Latin phrase *primum non nocere,* to the field of Earth Sciences. In recognition of her many achievements, Prof. Z. Rączkowska was elected to the board of many scientific organisations and served as the President of the Association of Polish Geomorphologists, the Polish representative in the Executive Board of the Carpathian-Balcan Geomorphological Commission, a member of the IAG Carpatho-Balkan-Dinaric Regional Working Group, a member of the Geographical Commission of the Polish Academy of Arts and Sciences, and a member of the Geographical Sciences Committee of the Polish Academy of Sciences.

Prof. Z. Rączkowska's main scientific interests focused on the processes that shaped the relief of mountain areas, particularly in high mountains. Her research took her to the Tatra Mountains, the Southern Carpathians, the Italian and French Alps, the Scandinavian Mountains, the Pyrenees, the Cairngorms in Scotland, the Khangai Mountains in Mongolia, the Hengduan Mountains in China, as well as the Himalayas and the Meghalaya Plateau in India. She studied contemporary morphogenetic processes in high mountains, under environmental conditions that can be described as periglacial (e.g., Rączkowska, 1995, 2007; Pech et al., 2003; Gądek et al., 2009, 2016, 2017; Rączkowska et al., 2012; Rączkowska & Joshi, 2016; Rączkowska & Cebulski, 2022; Rączkowska, 2022), she studied the dynamic relationship between geomorphological processes and vegetation in mountain environments (e.g. Kozłowska & Rączkowska 2002, 2006), and investigated the morphogenetic systems associated with mountain areas subjected to diverse anthropogenic pressure (e.g. Łajczak et al., 2014; Rączkowska et al., 2018; Rączkowska, 2019).

Special issue content

The articles contained within this special issue are reflective of Prof. Z. Rączkowska's research interests. These studies are intended to fill the gap between landform development and landscape changes associated with natural forces and human activities in the Central European Mountains. The papers are grouped into four general categories: (a) the influence of climate change on glacial landforms and snow avalanches, (b) the contemporary evolution of slopes in high mountains, (c) the development of mid-mountain relief under the impact of natural and anthropogenic forces as well as its recent changes in the context of sustainable development and (d) changes in fluvial systems in mountains and their forelands.

Climatic changes leave traces of their impacts on mountain landscapes. This effect is most obvious in the case of alternating glacial and interglacial climates during the Quaternary as well as climate change over the past millennium, specifically defined within the range encompassing the extremes of the Little Ice Age and warm phase of the present-day Holocene. In particular, changes in the extent of glaciers and the frequency of avalanches contribute significantly to the distinctiveness of high mountain landscapes (French, 2017). This is exemplified by the work of Kłapyta et al. (2023), who used a geomorphological mapping and clast morphology analysis in conjunction with glacier surface reconstruction to provide the extent and altitude of the equilibrium line of the Jupania palaeoglacier in the Maramureş Mountains in Romania during the late Pleistocene. The study finds well-preserved terminal moraines that mark the extent of the glacial front at ~1400 m a.s.l. and documents the former presence of small cirques formed by palaeoglaciers. Komac and Zorn (2023) provide insights into the effects of climatic changes on snowpacks by analysing the relationship between the North Atlantic Oscillation and the maximum snow depth in Slovenian Alps over the past two centuries, the relationships between maximum snow depth and avalanches over the past three decades, and a study of extreme snow avalanches in January 2021. An interesting conclusion is that the recent warming climate has led to precipitation at higher elevations in winter, resulting in the occurrence of major wet snow avalanches in winter, rather than in early spring as was more common in the past. Such avalanches can travel great distances because of their extraordinary mass and liquidity, often reaching the valley floor and damming watercourses.

Rock walls and talus slopes are the most common features of high-mountain relief (Ballantyne, 2002). Their evolution depends on both geology and the climate and involves the transfer of coarse-grained detritus between cliffs and the talus slope via rockfalls and debris flows. In this special issue, Gądek et al. (2023) present the results of the first large-area monitoring of rock slopes using terrestrial

laser scanning in the High Tatra Mountains, which have not been glaciated for thousands of years. The results demonstrate that the rate of retreat of granitoid slopes over the same period ranged from 0.00013 ma^{-1} to 0.004 ma^{-1}. The spatial variation in the number and size of cavities was related primarily to the density of cracks within the rock slopes. Kędzia et al. (2023) present the first results of the lichenometric dating of debris flows and their periods of activity on the southern slopes of the High Tatra Mountains over the past two centuries. The greatest debris flow activity was found to have occurred during the Little Ice Age and in the last two decades. The general agreement of these results with the dating of debris flow activity in the northern slope of the Tatra Mountains indicates that periods of increased debris flows are at least regionally significant (e.g. Gądek et al., 2016). Łajczak et al. (2023) analysed how landslide-debris flows on the Babia Góra Mt. in the Polish Carpathians functioned during the last 150 years. The Cylowa Zerwa landslide-debris flow occurred at an altitude of 1430-1024 m a.s.l. and is distinguished by the clear bipartite nature of its relief. The upper part of this landform includes step-like, arranged, and slumped (backwards-rotated) rock packages, whereas the lower and middle parts resemble landforms that are characteristic of debris slides or even debris flows. The study also found that the middle and lower parts of this landform have been subject to cyclical activations every ~45 years during the last 150 years.

Landscapes can be described as a palimpsest, and they reflect the effects of newer layers of management superimposed upon older layers of management and environmental change (Gregory, 2010). Thus, an interpretation of landscape histories requires multiple approaches. Migoń et al. (2023) look to bridge the gap between long-term landform evolution, climatic imprints, and human impacts on relief and the overall geomorphological system of the Sowie Mountains. They found that the seemingly monotonous Sowie Mountains exhibit considerable geomorphological diversity and may serve as a representative example of the complex relief that can develop on predominantly gneissic bedrock due to the effects of partial glaciation, periglacial conditions, and diverse human activities including agriculture, mining, and military use. Anthropogenic impacts in the form of population density and land use are direct drivers of environmental change in mountains (Lambin & Geist, 2006). The effects of these activities in the context of land degradation is a pressing issue (Sims et al., 2019), and is examined in the context of sustainable development goals achieved in the Polish Western Carpathians over the past 30 years by Bucała-Hrabia (2023). The analysis of land use changes in three mountain catchments during the transition from centrally planned to free-market economics indicates that the vast majority of changes, especially those related to the withdrawal of agriculture, have resulted in land improvement. Minor changes leading to land degradation were associated with increasing populations in the form of spreading settlements.

The multi-period changes that occur in the natural environment under the influence of natural and anthropogenic factors also affect the fluvial systems present within mountain ranges and their forelands (Macklin et al., 2006). The decreasing land use share of cultivated land reduces the amount of debris supplied to the river channel, which is an important factor that affects the maintenance of braided channels (Leopold & Wolman, 1957). This was evident in the study by Gorczyca et al. (2023), which showed that the current environmental conditions and human impact in the Białka River channel, the last braided river in the Polish Carpathians, do not favour the maintenance of existing braided sections. The ongoing conversion from braided to single channels is primarily associated with changing regulations in some sections as well as former gravel extraction. Furthermore, land use changes, such as the expansion of grasslands and forests at the expense of cultivated land, have limited the supply of sediments to river networks in recent decades. The impact

of Holocene climate change on the development of the Stryi River alluvial fan in the foreland of the Eastern Carpathians in Ukraine is documented in the study conducted by Gębica et al. (2023). The reconstruction presented by the study indicates increased river activity at around 8300, 5400 and 2800 BP, which are correlated with the beginning of humid phases and floods in the upper Vistula and upper Dniester basins in the foreland of the Carpathians, as well as floods recorded in lake sediment in the northern forelands of the Alps.

Future research directions

The findings presented by authors in this special issue may become the foundation for further studies on the role that natural factors and diverse human activities play in shaping the landforms and landscapes of the Central European Mountains. These studies have shown that our understanding of the periglacial transformation of relief as well as contemporary geomorphological processes is still insufficient, especially in low-altitude isolated mountain massifs where traces of Pleistocene glaciation have been identified. Such research is particularly important in light of projected climate change scenarios that predict increased temperatures and precipitation variability. In-depth work on the anthropogenic transformation of relief is needed to improve our knowledge of the geomorphological dimension of human impact, its influence on geomorphic systems, and the persistence of anthropogenic landforms. Furthermore, it is also necessary to investigate the link between climate, land use/land cover, and landforms in the context of the sustainable development of mountain areas. This is a particularly complex problem in Central Europe, where the varied anthropopressure along the steep altitudinal gradient of mountain areas is superimposed on the varied anthropopressure associated with historical changes in socio-economic systems. Indeed, the magnitude, mode, and timeframe of morphological adjustments are likely to vary considerably between different geomorphic elements of the landscape as well as between different mountain ranges. We hope that the methods, ideas, and information presented in these studies will inspire further research on the multiple drivers of change of landforms and landscapes in mountain areas.

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Editors' note:
Unless otherwise stated, the sources of tables and figures are the authors', on the basis of their own research.

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