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RELIEF OF CZECHIA: QUANTITATIVE EVALUATION IN THE GIS ENVIRONMENT

DEMEK, J., BALATKA, B., KIRCHNER, K., MACKOVČIN, P., PÁNEK, T., SLAVÍK, P. (2011): Relief of Czechia: quantitative evaluation in the GIS environment. Geografie, 116, No. 2, pp. 111–129. – The authors used a new GIS-based geomorphological map of Czechia in the scale of 1:500,000 (Demek, Balatka, Kirchner, Mackovčin, Pánek, Slavík 2009) for computer aided quantitative evaluation of the relief of the country. The analysis showed that erosion landforms prevail in Czechia (77.14% of the Czech territory). Summit and piedmont planation surfaces (etchplain, rock pediments, and cryopediments) that take 8.87% of the Czech territory were quantitatively evaluated over the whole Czech territory for the first time. The most common accumulation landforms were loess surfaces (8.04%) and fluvial landforms like floodplains and accumulation river terraces (8.20% of state territory). Polygon layer of the new GIS-based map enabled the evaluation of the geomorphodiversity of the Czech territory.
KEY WORDS: Digital geomorphological maps – computer aided methods – Czechia – geomorphodiversity.

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1. Introduction

In the last couple of years the application of GIS technologies has provided geomorphological research with a series of new possibilities for quantitative landform analysis and construction of geomorphological databases (Dikau 1992; Gustavsson, Seijmonsbergen, Kolstrup 2008; Kertész, Markus 1992; Minár, Evans 2008; Vitek, Giardino, Fitzgerald 1996; Voženílek et al. 2001). The first and the last general geomorphological map of Czechia in the scale 1:500,000 was published 45 years ago (Stehlík, ed. 1965). The application of GIS technologies has become an important tool for data management and numerical data analysis for purposes of geomorphological research (see Hengl, Hannes, eds. 2009) from that time. The authors compiled the first GIS-based general geomorphological map of the Czech Republic in the scale 1:500,000 (Demek, Balatka, Kirchner, Mackovčin, Pánek, Slavík 2009) for the new Landscape Atlas of the Czech Republic (Hrnčiarová, Mackovčin, Zvara et al. 2009) during years 2007–2009. Geomorphological mapping run in the scale of 1:200,000 resulting in the final atlas map in the scale 1:500,000. A general geomorphological map forms the strongest scientific source of information and the best explanatory presentation of landforms and relief development. Obtained information was digitized in the GIS environment using products of the ESRI Company (especially ArcGIS 9.2) in the Department of GIS Application of The Silva Tarouca Research Institute for Landscape and Ornamental Gardening, public research institute in Průhonice, branch Brno (Czechia) and in ESPRIT Company in the town of Banská Štiavnica (Slovakia). This GIS-based map enabled the authors quantitatively evaluate the relief of Czechia and the geomorphodiversity of the Czech territory.

2. Methods

Methods used to produce the new GIS-based geomorphological map of Czechia (Demek, Balatka, Kirchner, Mackovčin, Pánek, Slavík 2009) included a combination of both topographic and thematic map interpretation, use of aerial and satellite photographs, field mapping of some geomorphological features, the use of previously published geomorphological surveys and digital data handling. Principles of the IGU Commission on Geomorphological Mapping published in the Project of the unified key to the detailed geomorphological map of the World (Bashenina et al. 1968; Demek, ed. 1972; Demek, Embleton, Kugler, eds. 1982) were used for compilation of the key. Basic mapping unit represents a discrete landform, i.e. a discrete morphologic feature that is a functionally interrelated part of the land surface formed by a specific geomorphological process or set of processes (Hengl, Hannes, eds. 2009). Shapes and locations of landforms are shown by contour lines and spot-heights. In addition to the contour lines information on slope gradients is given. Slopes were divided according to their inclination into three gradient categories 2–5, 5–15, 15 and more degrees and expressed by various colour intensities (hue). The GIS handled all geomorphological data as separate objects. Thus, all attributes and distances among them are easily measurable. Landforms were further divided according to their origin into genetic groups in agreement with the above mentioned principles of the IGU Commission (Fig. 2). Geomorphological mapping symbols were partly developed specifically for this project and the authors partly used the digital symbol library of Létal, Voženílek (2002) and collected in the symbol library as part of the ArcGIS 9.2 extension that was used to produce the map in GIS environment. Using digital image processing techniques, different information layers were developed. Thus, landforms are in the map in three layers – polygon, point symbol and line symbol layer. The base of the map forms polygon layer. Polygon is a multi-sided figure representing an area on the map (Burrough, Rachael 1998, p. 304). The polygon layer is a map layer that displays polygon based spatial elements (landforms) that are mapped at scale. Landforms too small to be included at scale, but important from the point of view of relief genesis and processes, are presented by symbols in the point and linear layers. Each polygon, line or point is than linked to data tables that present additional data on the specific landform (see Table 1). GIS software was used for the comparative spatial and quantitative analysis of these information layers. Process/genesis is indicated by colours because

Table 1 – Quantitative evaluation of landforms showed on the map Geomorphological conditions in the Landscape Atlas of the Czech Republic (2009)

1. Erosion Landforms

No	Code	Name of landform	Number of landforms	Min.–max. area in km²	Total area in km²	Percent of the territory
1	A28 A09	Erosion slope (inclination 5–15°)	972	0.2–7,301.9	20,473.6	25.82
2	A28a A08	Erosion slope (inclination 2–5°)	500	0.3–4,519.3	18,309.6	23.08
3	A29	Erosion slope (inclination more than 15°)	981	0.3–840.7	9,268.6	11.72
4	A14	Etchplain (inclination 0–2°)	1,056	0.3–130.3	3,076.2	3.88
5	A14a	Summit planation surface (in the Carpathians)	6	0.3–1.3	4.7	0.01
6	A15	Rock pediment	483	0.1–112.1	1,859.7	2.36
7	A16	Glacis d'érosion	43	0.7–109.9	415.2	0.53
8	A51	Cryopediment plane	121	0.7–300.8	2,071.0	2.63
9	A53	Cryoplanation terrace, cryoplanation summit flat	5	1.1–2.2	8.9	0.01
10	A52	Cryopediment back scarp	21	0.5–20.5	72.3	0.09
11	A17	Structural plane	340	0.3–576.1	3,443.0	4.35
12	A23 L23	Structural scarp	84 157	0.3–19.0	312.8	0.40
13	A19	Monadnock	1,357	0.2–9.1	671.0	0.85
14	A24 L24	Mesa	41 583	0.3–5.3	201.5	0.26
15	A21 L21	Cuesta escarpment	39 101	0.3–7.7	72.2	0.09
16	A22	Cuesta back slope	32	1.1–140.3	588.4	0.75
17	A18 L18	Structural range	478 626	0.3–53.4	1,317.3	1.67
18	A20 L20	Structural ridge (crest)	6 34	0.4–2.4	6.5	0.01
19	A25	Klippe	7	0.2–1.2	3.9	0.00
20	A26	Mendip	17	0.3–2.3	14.8	0.02
21	A27 B27	Exfoliation dome, ruware, bornhardt	12 47	0.3–2.6	8.0	0.01
22	A43 B43	Pseudokarst rock city	16 21	0.7–111.9	302.7	0.38
23	A47	Karst canyon, gorge	2	1.0–16.5	17.5	0.02
24	A48 B48	Landslide, group of landslides	12 856	0.9–3.5	17.0	0.02
25	A69	Erosion surface on ground moraine	30	1.0–20.4	136.7	0.17
26	A57 B57	Nivation hollow	1 67	0.6–0.6	0.6	0.00
27	A61	Roche moutonnée	6	0.1–2.7	5.0	0.01
28	B58	Cirque of Pleistocene glacier with moraine	15	–	–	–
29	B30	Meander core	19	–	–	–
30	B35	Karst doline	4	–	–	–
31	B36	Abyss	3	–	–	–
32	B55	Tor, castle koppie	734	–	–	–

No	Code	Name of landform	Number of landforms	Min.–max. area in km²	Total area in km²	Percent of the territory
33	B41	Mogote	2	–	–	–
34	L33	Gully	1,528	–	–	–
35	L56	Dell	368	–	–	–
	Total					79.14

2. Accumulation Landforms

36	A74	Surface of loess	361	0.4–331.6	6,370.3	8.04
37	A65	Floodplain	124	0.3–1,675.6	3,791.0	4.79
38	A64b	River accumulation terrace Middle Pleistocene	357	0.3–37.8	1,291.1	1.64
39	A64c	River accumulation terrace Lower Pleistocene	192	0.2–58.9	650.4	0.82
40	A64a	River accumulation terrace Upper Pleistocene	85	0.3–82.7	533.0	0.68
41	A72	Surface of aeolian sands	47	0.5–140.1	470.4	0.60
42	A71	Outwash plain, sandur	51	0.4–107.7	469.7	0.60
43	A62	Proluvial plain	35	0.5–61.8	340.0	0.43
44	A75	Surface of peat bogs	87	0.3–22.4	240.2	0.30
45	A63	Alluvial (proluvial) cone	73	0.3–2.8	181.7	0.23
46	A64	River accumulation terrace (unclassified)	64	0.3–18.6	154.9	0.20
47	A66	Debris slope	44	0.4–28.4	132.2	0.17
48	A64d	River accumulation terrace, Neogene	30	0.3–15.6	59.1	0.07
49	A73 B73	Sand dune	17 121	0.4–1.3	10.7	0.01
50	A68 L68	Block stream, mud flow	1 2	0.6–0.6	0.6	0.00
51	B67	Block field, felsenmeer	921	–	–	–
52	L76	Organic deposits in oxbow	67	–	–	–
	Total					18.58

3. Neotectonic Landforms

53	A01	Fault scarp	541	0.3–19.0	907.3	1.15
54	A06	Slope of anticline	3	15.8–42.4	90.4	0.11
55	A07	Slope of syncline	1	30.1–30.1	30.1	0.04
56	L02	Axis of megaanticline	21	–	–	–
57	L03	Axis of megasyncline	7	–	–	–
58	L04	Axis of anticline	15	–	–	–
59	L05	Axis of syncline	12	–	–	–
	Total					1.30

4. Neovolcanic Landforms

60	A10	Neovolcanic knob and cone	219	0.1–16.0	102.0	0.13
61	A11	Exudates subvolcanic body	364	0.1–1.9	93.5	0.12
62	A12	Exposed vein, wall	2	0.3–0.3	0.6	0.00
	Total					0.25

5. Man-made Landforms

No	Code	Name of landform	Number of landforms	Min.–max. area in km²	Total area in km²	Percent of the territory
63	A77a B77a	Stone quarry active	7 321	0.4–4.25	11.4	0.01
64	B77n	Stone quarry non-active	1,324	–	–	–
65	A78a B78a	Gravel pit, sand pit active	22 108	0.6–10.7	49.7	0.06
66	A78n B78n	Gravel pit, sand pit non-active	16 294	0.7–4.9	27.7	0.04
67	A79 B79	Mine dump, setting pit	129 47	0.2–74.7	389.0	0.49
68	B79a	Mine adit, winding shaft active	15	–	–	–
69	B79n	Mine adit, winding shaft non-active	149	–	–	–
70	B80	Collapse sink, group of collapse sink	3	–	–	–
71	A81	Mining subsidence depression	2	0.7–3.0	3.6	0.00
72	A82	Loam pit, clay pit	310	1.5–2.4	9.1	0.01
73	A83	Open-cast mine	11	0.3–29.9	97.8	0.12
	Total					0.73

Explanation: A – polygonal layer, L – linear symbol layer, B – point symbol layer, – data from linear (L) and point (B) symbol layer, areal data not available

colour is the most eye-catching graphic variable. The age of landforms is given in letter code. During compilation of the final atlas map was required certain generalization of landforms according to their spatial extent and importance (e.g. monadnocks and mesas). Processing of the map in the GIS environment enabled to obtain new quantitative information on geomorphodiversity.

3. Relief of Czechia: basic quantitative data

3.1. Quantitative evaluation of erosion landforms

Erosion landforms are predominating on the territory of Czechia according to the quantitative relief evaluation in the GIS environment (see Tab. 1 and Fig. 3). The most common landforms are fluvial erosion slopes present over an area of 48,051.8 km² (63.62% of the Czech territory). Gentle fluvial erosion slopes inclined 2–5° (totalling 500 patches) take 18,309.6 km² (23.08% of the state territory). Patches in this group have mean area of 42.2 km². The most common landforms are fluvial moderate slopes inclined 5–15° (totalling 972 patches) that cover an area of 20,473.6 km² (25.82% of the Czech territory). Patches in this group are of the average area of 21.6 km². Steep slopes inclined more than 15° (981 patches) take 9,268.6 km² (11.72% of the country). Patches in this group are of the average area of 9.4 km².

Apart from erosion slopes, structural slopes are also common controlled by exposures of resistant bedrock. The map contains 241 localities of structural scarps in total 632.3 km long and spreading over an area of 312.8 km² (0.40% of the Czech territory).

Flat horizontal or gentle inclined (from 0.1 to 2°) erosion relief is present in the form of either polygenetic planation surfaces or structural flats. The summit polygenetic planation surfaces are represented by etchplain flats cutting old bedrock of the Bohemian Massif and the Moravian-Silesian terrane. The authors delimited 1,056 flats with the extent of more than 30 hectares (the larges flat has the extent of 130.3 km^2). Etchplain covers the area of 3,076.2 km^2 (3.88% of the Czech territory). Above a gently rolling etchplain conspicuously rise many monadnocks. Due to the high number of monadnocks a restriction of the smaller monadnocks was carried out by a computer and leaving 1,357 monadnocks with areas greater than 40 hectares only.

In the Carpathian's part of Czechia the top summit planation surface developed in the Javorníky Mts., where 6 flats on summits and mountain ridges larger than 30 hectares are present on the area of 4.7 km^2. Summit flats earlier interpreted by Czech geomorphologists as summit planation surfaces are now mostly shown in the map as structural surfaces controlled by subhorizontaly bedded sandstones.

An area of low relief developed upon gently tilted or horizontally bedded Cretaceous sedimentary rocks of the Bohemian Plateau especially in North Bohemia. Less resistant layers have been removed by erosion thereby revealing a more resistant stratum (e.g. quartzose block sandstones) forming structural plateaus. The map shows 340 structural planes that taking the area of 3,443.0 km^2 (4.37% of the Czech territory). Above flat structural relief rise on many localities isolated flat-topped hills (mesas) of different parameters. Due to the scale of the map a computer study was carried out leaving the authors with 624 mesas on the map (41 mesas greater than 30 hectares in the polygon layer and 583 mesas in the point layer). Mesas take the area of 201.5 km^2 (0.26% of the country).

Distribution of piedmont planation surfaces – rock pediments and glacis d'érosion, is shown on the map for the first time for the whole state territory. The authors delimited 483 rock pediments with a total area of 1,859.7 km^2 (2.36% of the Czech territory). On some localities rock pediments developed in two levels coalescing into a pediplain. Valley rock pediments originated by the recession of the scarp above are common in the Czech Republic. Rarer are glacis d'érosion developed by the migrating stream channels on less resistant rocks at the foot of slopes composed of more resistant rocks. The map shows 43 glacis d'érosion with the area of 415.2 km^2 (0.53% of the Czech territory). Cryopediments are piedmont planation surfaces developed in cold periods of the Pleistocene Epoch in permafrost conditions. The map shows 121 cryopediments of larger extent (see Table 1) that in polygon layer cover the area of 2,071.0 km^2 (2.63% of the Czech territory). There are also 21 localities of higher cryopediment backslopes represented on the map. These data show that piedmont planation surfaces represent an important part of the land-surface of Czechia. The authors incorporated also cryoplanation terraces and cryoplanation summit flats among planation surfaces. This general map shows only 5 localities of large cryoplanation terraces and cryoplanation summit flats in the Mts. Hrubý Jeseník and the Rychlebské hory Mts. covering the total of 8.9 km^2.

Structural denudation ranges developed in gently dipping strata. These landforms cover the area of 1,317.3 km^2 (1.67% of the Czech territory) and in both the polygon and linear layers are 1,184.6 km^2 long. There are also 140 localities of structural ridges with an asymmetrical cross section of escarpment and back slope (cuestas) on the map. Steep cuestas escarpments that cut across the strata cover the area of 72.2 km^2 (0.09% of Czech territory) and in both the polygon and linear layers are 376.9 km^2 long. The gentle long cuestas back slopes cover the area of 588.4 km^2 (0.75% of the Czech territory). Back slopes are partly dip slopes and partly planation surfaces.

The polygonal layer contains 6 localities of structural crests (6.5 km^2, 0.01% of the Czech territory) and linear symbol layer then 34 localities with the total lengths of crests of 51 km.

There are 7 klippens present in the Carpathians covering the area of 3.9 km^2 and 17 mendips of the area of 14.8 km^2 in the Carpathian's foredeep.

Rock cities are of the largest area in the genetic group of pseudokarst erosion landforms. The polygon layer contains 16 pseudokarst rock cities in the polygon layer (the area of 302.7 km^2, 0.38% of the Czech territory) and the point layer shows 21 localities. Small pseudokarst landforms are represented in point layer (see Table 1). These landforms are together with landforms of polygenetic or cryogenic origin very important for the geomorphodiversity of the Czech territory (e.g. 734 tors and castle koppies in the point layer).

In conclusion to this group of landforms it is necessary to mention the 1,528 gullies and gorges 2,996.1 km long and 368 expressive dells of the total of 612.8 km long. The number of dells is of course much higher within the territory of Czechia than the number of dells that could be shown on the general map.

3.2. Quantitative evaluation of accumulation landforms

Surfaces on loess are the most common accumulation landform in the relief of Czechia, especially in lowlands and low plateaus (a total of 6,370.3 km^2, 8.04% of the Czech territory). These surfaces mostly covered by fertile agricultural soils are commercially very important. Flat surfaces of floodplains covering an area of 3,791.0 km^2 follow (4.79% of the Czech territory). Surfaces of accumulation river terraces also represent a large areas (see Table 1), following the riverbeds of Czech rivers and covering 2,688.5 km^2 (3.41% of the Czech territory). Proluvial plains (340.0 km^2, 0.43% of the Czech territory) and proluvial cones (181.7 km^2, 0.23% of the Czech territory) from the group of fluvial landforms follow.

In parts of the country covered by inlandsis during the Pleistocene glacial periods are the most common accumulation landforms outwash-plains (sandurs). The map shows 51 localities covering the area of 469.7 km^2 (0.60% of the state territory).

Aeolian sands represent a smaller area, in some places with sand dunes (470.4 km^2, 0.60% of the Czech territory). In total 138 sand dunes covering in polygonal layer the area of 10.7 km^2 (0.01% of the Czech territory) are presented on the map. Relatively high is the number of polygenetic and cryogenic block fields (felsenmeeres) included into the point symbol layer (921 localities in total).

3.3. Quantitative evaluation of neotectonic landforms

Neotectonic landforms on the territory of Czechia are divided into two groups – block and fold landforms. From the group of block landforms are there are 541 localities of fault scarps of different heights and expressiveness shown on the map. From this number 461 fault scarps are shown in the polygonal layer and these landforms cover the total of 907.3 km^2 (1.15% of the Czech territory), another 80 localities are shown in the linear symbol layer. The total lengths of fault scarps reach 2,501.3 km.

From the group of fold neotectonic landforms group there are 13 localities of anticlinal slopes shown in the polygonal layer covering the area of 90.4 km^2 (0.11% of the state territory) and 1 locality of synclinal slopes (30.1 km^2, 0.04% of the Czech territory). In the linear symbol layer there are axes of 21 megaanticlines marked (total lengths of 378.8 km) and the axes of 7 megasynclines (total lengths of 342.0 km). Further in this layer are shown axes of 5 anticlines of normal folds (total lengths of 282.8 km) and 12 synclines (total of lengths 468.0 km).

3.4. Quantitative evaluation of neovolcanic landforms

In the genetic group of neovolcanic landforms are traditionally included landforms originated by volcanic activity in the Tertiary and Quaternary Periods. In reality these landforms were substantially changed by erosion into erosion and exudated landforms. Nevertheless these landforms are important from the geomorphological diversity (geomorphodiversity) point of view. The authors showed 129 neovolcanic knobs and cones of the total area of 102.0 km^2 (0.13% of the Czech territory) in the map. From the subgroup of exudated subvolcanic bodies the landforms greater than 12 hectares were marked in the map. The map shows 364 exudated subvolcanic bodies covering the area of 93.5 km^2 (0.12% of the Czech territory). Separately are presented exudated neovolcanic vein and wall (with an area of 0.5 km^2, 0.01% of the Czech territory).

3.5. Quantitative evaluation of anthropogenic landforms

Man-made landforms are very dynamic relief feature undergoing permanently rapid changes (see Table 1). New anthropogenic landforms are constructed; old landforms are recultivated or filled up (reclaimed). The authors met problems in the mapping of the anthropogenic pressure on the relief. Maps of mineral deposits of Czechia in the scale 1:50,000 are out of date, because the situation in mineral extraction industry rapidly changed after 1989 (Smolová 2008). The authors used incomplete digital database of the Czech Geological Survey and actual aerial photographs. A lot of anthropogenic landforms were recultivated. On the other hand in places with the concentration of man-made landforms some generalization was necessary due to the scale of the map.

The map shows 328 active stone quarries covering the area of 11.4 km^2 (0.1% of the Czech territory). The authors delimited many more non-active stone quarries (1,324 localities), but this number keeps changing due to filling-up and recultivation. Larger pressure on the relief is made by active sand and gravel pits that cover the area of 49.7 km^2 (0.06% of the Czech territory). The map shows 176 non-actives sand and gravel pits (area 27.7 km^2, 0.04% of the Czech territory). Loam pits and clay pits are also included in the map (310 localities, area 9.1 km^2, 0.01% of the Czech territory). Typical man-made landforms are large open-cast mines in West Bohemia. The map shows 11 great open-cast mines covering the area of 97.8 km^2 (0.12% of the Czech territory). Large areas are also taken by mine dumps and setting pits (total 389 km^2, 0.49% of the Czech territory). The point symbol layer contains further anthropogenic landforms.

4. Quantitative evaluation of geomorphodiversity

The authors used the polygon layer for quantitative evaluation of spatial structures of the relief in GIS environment together with quantitative evaluation of individual landforms and groups of landforms. In general spatial structures of the relief are associated with the composition and configuration of landforms. Composition refers to the number and occurrence of different

Table 2 – Elements of geodiversity (Serrano, Ruiz-Flano 2007)

Topography	Energy Roughness	
Geology	Earth material	Minerals Lithology (rocks) Superficial deposits
	Tectonics Structures	
Geomorphology	Morphostructures Morphogenetic systems Processes Erosion landforms Accumulation landforms Micro-landforms	
Hydrology	Water states	Water Snow Ice Glaciers
	Hydrologic elements	Oceans Seas Rivers Springs Wetlands Lakes
Soils	Orders Suborders	

types of landforms, while configuration encompasses the spatial distribution or spatial character within the relief. In this context numerous mathematical indices have been developed allowing the objective description of different aspects of relief structures and patterns (geomorphometry – Hengl, Hannes, eds. 2009) and coming to the terms of geodiversity and geomorphodiversity. Geodiversity is a rather new, emerging topic in Earth sciences (Cílek 2002; Ložek 2006; Hjort, Luoto 2010), especially in geomorphology. Elements of geodiversity see Table 2. The relief is an important element of geodiversity (Serrano, Ruiz-Flano 2007). Geomorphodiversity is than a critical and specific assessment of geomorphological features of a territory, by comparing them in an extrinsic and in intrinsic way, taking into account the scale of investigation, the purpose of research and the level of scientific quality (Panizza 2009a, b).

An increasing attention is paid to the need to understand patterns of geomorphodiversity on different types of Earth's relief. The authors quantified the spatial variation of geomorphodiversity in Czechia using two different measures – landform density and number of genetic classes. For computing authors used a spatial grid based on geographical coordinates from the official Czech Information System of Nature Protection (DISOP). The grid contains 679 cells within the territory of Czechia. The basic cell on the 50th parallel north is represented by the area of 12 × 11.1 km. Therefore the average area of the grid cell is 133.5 km^2. The maps are derived from the polygon layer of the atlas map Geomorphological Conditions (Demek, Balatka, Kirchner, Mackovčin, Pánek, Slavík 2009) and related geomorphological database.

4.1. Landform Density (HPT)

A landform represents in GIS-environment a patch which is covered by one single code number (see Table 1) in the polygon layer. Relief of Czechia is composed of a mosaic of landforms (patches). The landforms density (HPT) expresses the number of landforms (patches) within the entire reference unit (window of 12 × 11.1 km). It is calculated as

$HPT = \frac{a}{n}$ (Eiden, Kayadjanian, Vidal 2010, p. 2)

where HPT = Landform Density, n = Number of Landforms, a = reference unit (area).

Landform Density increases with a greater number of landforms within the reference area (grid cell).

In general index of landform density it depends on the "grain size" of the input data from the polygon layer, i.e. the size of the smallest landform mapped (e.g. 13 hectares in the neovolcanic group or 0.21 hectares in the case of monadnocks). The number of landforms in grid windows varies from 1 to 20 per grid cell. Topographically, the high-geomorphodiversity sites occurred in places where both natural erosion and accumulation processes and anthropogenic activities play a major role in relief development (see Fig. 2). Cells with a high landform density (from 15 to 20) are concentrated in the northwestern part of the Czech territory (the Ore Mts. and the Ohře Rift, volcanic mountains the Doupovské hory Mts. and the České středohoří Mts.). A high density of landforms is concentrated in the Bohemian Karst with karst landforms

Table 3 – Landform Density

Number of land-forms in a grid cell	Frequency (N – integer)	Number of land-forms in a grid cell	Frequency (N – integer)
1	3	11	60
2	18	12	34
3	19	13	26
4	36	14	16
5	64	15	6
6	85	16	4
7	83	17	3
8	79	18	0
9	83	19	1
10	59	20	1

Table 4 – Number of landform classes (total geomorphodiversity – NGC)

Number of landform classes in a grid cell	Frequency (units)
1	113
2	267
3	225
4	63
5	11

around the deeply incised Berounka River. valley and in dissected Cretaceous plateau of Polomené hory (Protected Landscape Area Kokořínsko) with rock cities and gorges in the Central Bohemia. In the Eastern Bohemia the large density of landforms is presented in the cuesta landscape of the Jestřebí hory Mts. The most common are the cells with 5, 6, 7, 8 and 9 landforms that prevail in the central and southern part of the country (see Map 2). The index is a good reflection of the extent to which relief is fragmented and is therefore fundamental for the assessment of relief structures, enabling comparisons of units of various sizes.

4.2. Number of genetic landform classes (total geodiversity – NGC)

Another measure of capturing the geomorphodiversity was used to count the number of different categories, in our case genetic landform classes within a reference unit. The more classes there are the more diverse the area is. The advantage of this index is that it can be calculated and interpreted easily. However the result might be misleading, because the area covered by each class and therefore its importance is not considered. Even if a certain landform class covers only the smallest possible area (e.g. monadnock), it is counted in. The authors divided landforms into 5 classes (see Table 1 and Table 4). The cells with the largest number genetic classes (4 and 5) are again concentrated in the northwestern part of the country (the Ore Mts. and the Ohře Rift, volcanic mountains of the Doupovské hory Mts. and the České středohoří Mts.). Areas with 2 and 3 landform classes prevail in Czechia (see Fig. 3).

5. Conclusion

The land-surface that surrounds us is essential to the life and activity of our society and the understanding of its characteristics and processes are important for sustainable development. The compilation of the new GIS-based geomorphological map (Demek, Balatka, Kirchner, Mackovčin, Pánek, Slavík 2009) enabled quantitative evaluation of the relief of the Czech Republic in Central Europe and has provided new information. The largest area in Czechia is covered by fluvial erosion slopes (60.56% of the Czech territory), out of which the largest area is covered by slopes inclined from 5 to 15° (25.82%). Surfaces of the Pleistocene loess covers (6,370.3 km^2, 8.08% of the Czech territory) follow on the second place as the evidence of large wind activity in the periglacial landscapes during the cold periods of the Pleistocene. Types of planation surfaces namely polygenetic and cryogenic surfaces on the territory of Czechia were cartographically represented for the first time. Polygenetic planation surfaces are the remains of etchplain and summit planation flats in the Carpathians and are also piedmont planation surfaces (e.g. rock pediments, glacises d'erosion and cryopediments). The polygon layer of the GIS-based map enabled the evaluation of geomorphodiversity of the Czech territory. GIS is thus an important instrument of geomorphological survey. Further development in digital GIS-based geomorphological maps may lead to standardized automated terrain-analysis techniques and more insight into evolution of the Czech land surface that formed for a long time.

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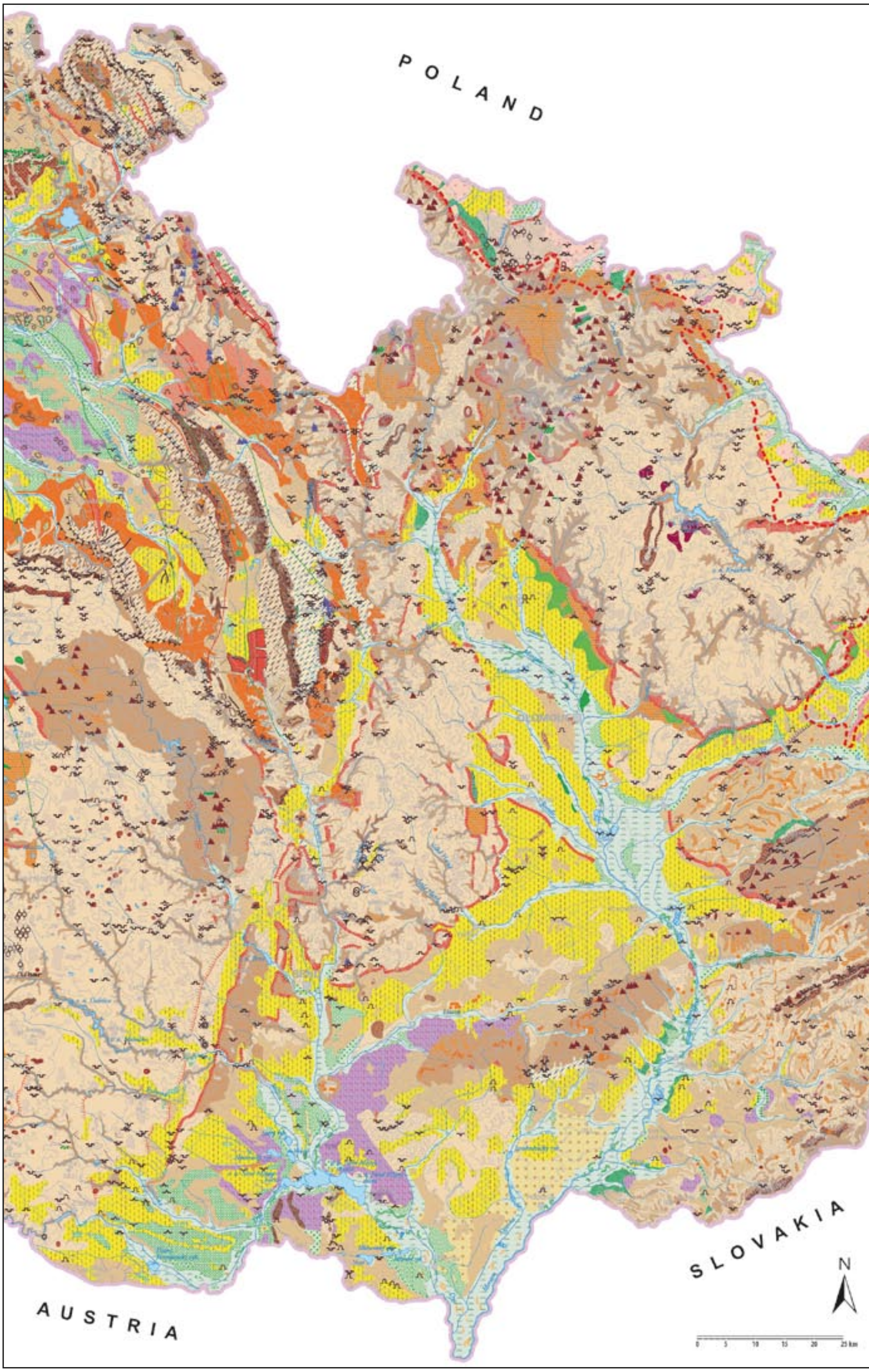

Fig. 1 – Example of the GIS-based geomorphological map of Czechia (Demek, Balatka, Kirchner, Mackovčin, Pánek, Slavík 2009)

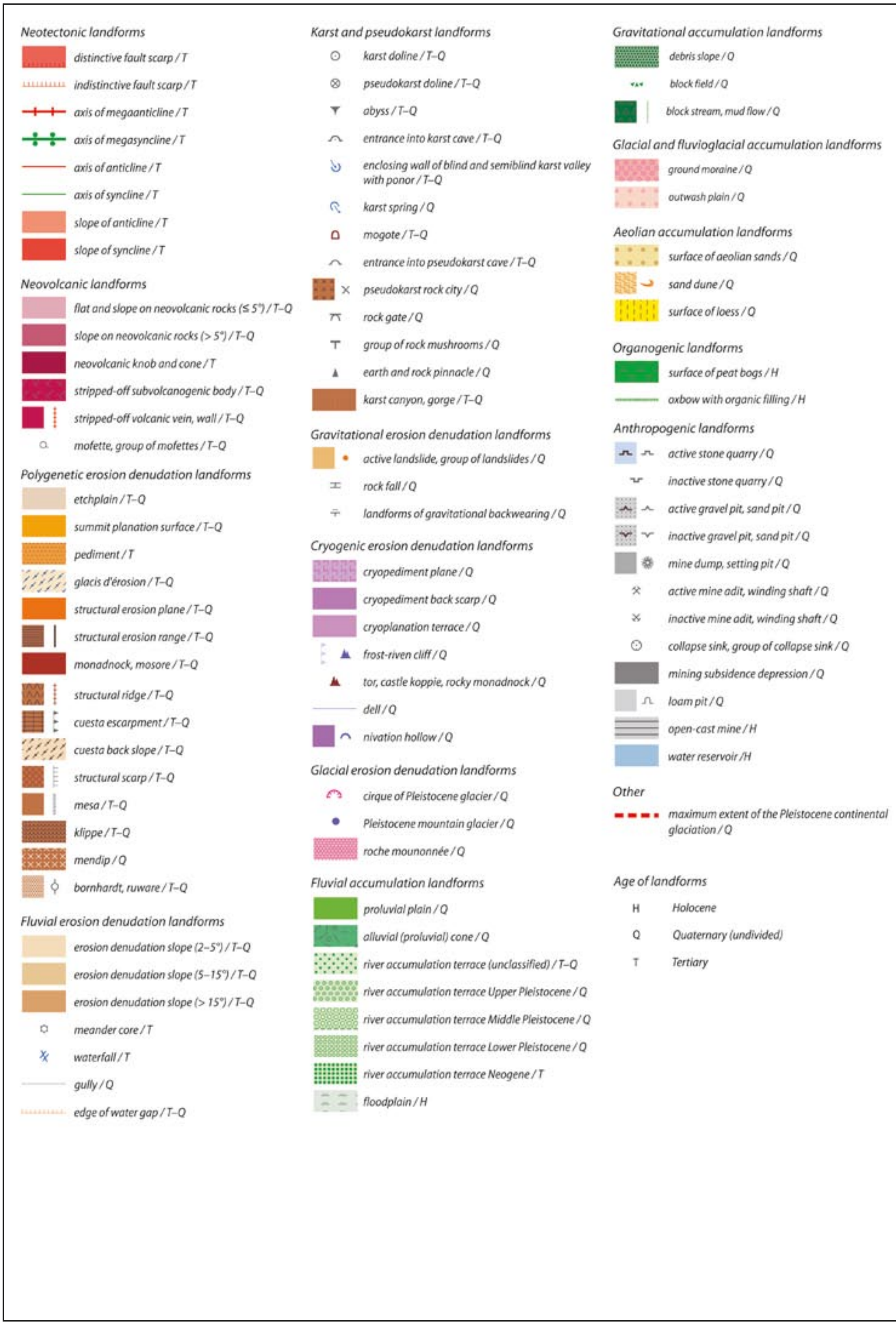

Fig. 2 – Legend to the GIS-based geomorphological map of Czechia (Demek, Balatka, Kirchner, Mackovčin, Pánek, Slavík 2009)

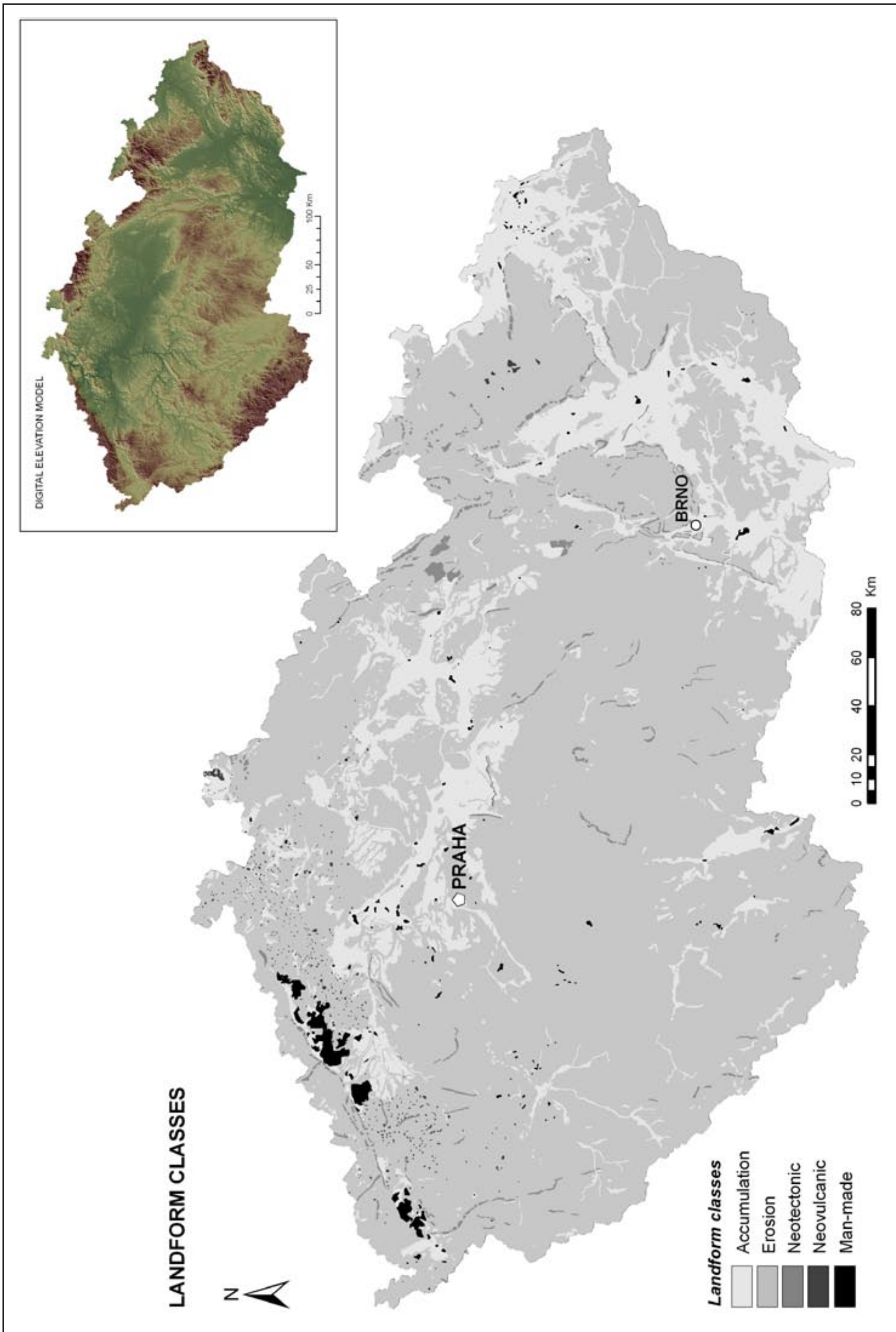

Fig. 3 – Distribution of landform classes on the territory of Czechia

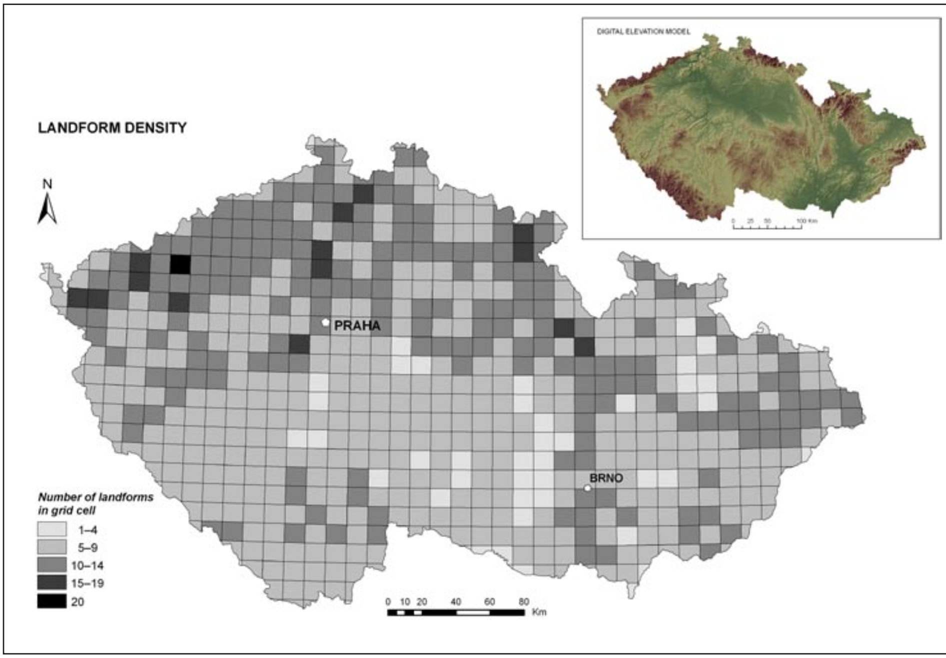

Fig. 4 – Landform density (HPT) on the territory of Czechia

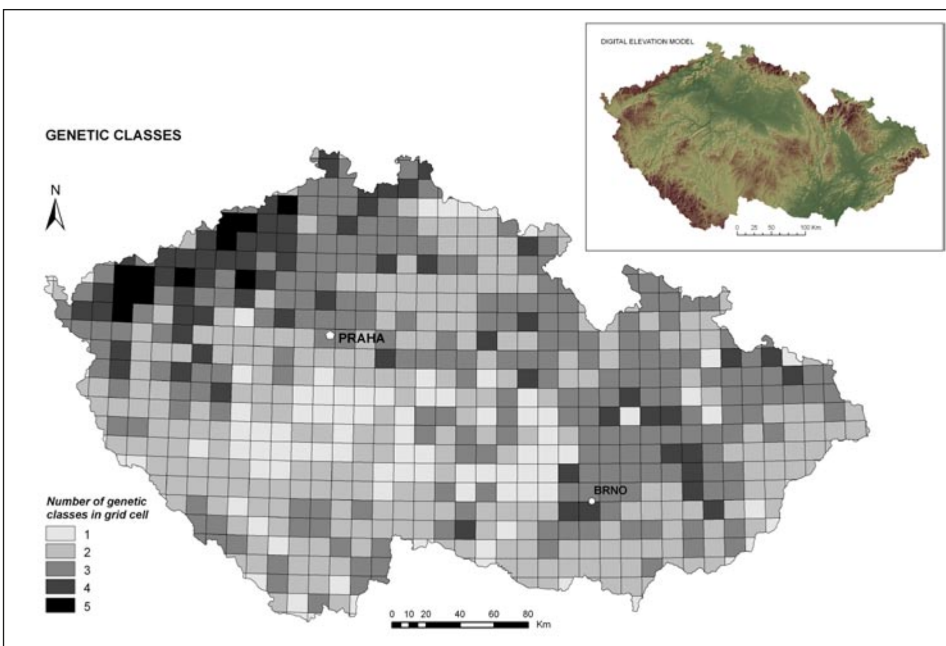

Fig. 5 – Number of landform genetic classes (total geomorphodiversity – NGC) on the territory of Czechia

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S h r n u t í

GEORELIÉF ČESKA A JEHO KVANTITATIVNÍ HODNOCENÍ V PROSTŘEDÍ GIS

V posledních letech aplikace technologií GIS poskytla geomorfologům řadu nových možností pro kvantitativní hodnocení georeliéfu a zpracování geomorfologických databází (Minár, Evans 2008).

Autoři v rámci prací na novém Atlasu krajiny České republiky (Hrnčiarová, Mackovčin, Zvara et al. 2009) zpracovali v letech 2007–2009 novou obecnou geomorfologickou mapu Česka v prostředí GIS (Demek, Balatka, Kirchner, Mackovčin, Pánek, Slavík 2009). Tvorba mapy probíhala v měřítku 1 : 200 000 s výslednou atlasovou mapou v měřítku 1 : 500 000. Legenda geomorfologické mapy byla sestavena podle zásad Komise pro geomorfologické mapování Mezinárodní geografické unie (IGU), uvedených v projektu Jednotného klíče k po-

drobným geomorfologickým mapám světa (Bashenina et al. 1968; Demek, ed. 1972; Demek, Embleton, Kugler, eds. 1982). Základní mapovací jednotkou byly tvary georeliéfu. Povrchové tvary jsou v mapě vyjádřeny ve třech vrstvách, a to plošné, lineární a bodové. Pro vyjádření geneze tvarů byly v mapě použity barvy. Při konečném zpracování výsledné mapy bylo potřeba přistoupit k určité generalizaci obsahu podle plošného rozsahu a významu (např. suků), což se přirozeně projevilo i v kvantitativních údajích.

Digitální mapa poskytla možnost kvantitativního hodnocení georeliéfu Česka a geomorfodiverzity státního území. Podle mapy jsou na území republiky v georeliéfu nejvíce zastoupené fluviální erozně-denudační svahy, které zabírají plochu 48 051,8 km^2 (tj. 63,62 % území státu). V mapě jsou tyto erozně denudační svahy rozdělené podle sklonu. Mírně skloněné svahy o sklonu 2–5° (celkem 500 ploch) zabírají 18 309,6 km^2 (tj. 23,08 % území státu). Největší rozšíření mají středně skloněné svahy o sklonu 5–15° (972 ploch), které celkově zabírají plochu 20 473,6 km^2 (tj. 25,82 % rozlohy státu). Svahy se sklonem větším než 15° (981 ploch) zabírají 9 268,6 km^2 (tj. 11,72 % rozlohy státu).

Vedle erozně-denudačních svahů se v georeliéfu Česka vyskytují i strukturní svahy vázané na výchozy odolných hornin. V mapě je uvedeno 241 lokalit strukturních svahů o celkové délce 632,3 km, které dohromady zabírají v polygonové vrstvě plochu 312,8 km^2 (1,67 % rozlohy státu).

Erozně-denudační plochy o sklonu 0–2° se na území státu vyskytují jednak jako polygenetické zarovnané povrchy a jednak jako strukturně-denudační plošiny. Z vrcholových polygenetických zarovnaných (sečných) povrchů jsou to především plošiny holoroviny v České vysočině a moravsko-slezském teránu. Autoři v mapě vymezili 1 056 plošin o rozloze větší než 30 hektarů (největší plošina zabírá plochu 130,3 km^2), které celkově mají plochu 3 076,2 km^2 (tj. 3,88 % povrchu státu). V karpatské části republiky se vrcholové sečné povrchy nacházejí v Javorníkách, kde 6 plošin větších než 30 hektarů zabírá plochu 4,7 km^2. V mapě je poprvé vyznačené rozšíření úpatních povrchů na celém území Česka, a to jak skalních pedimentů, tak i erozních glacisů. V mapě je znázorněných 483 pedimentů zabírajících plochu 1 859,7 km^2 (2,36 % plochy státu). Místy se skalní pedimenty vyskytují ve dvou stupních na sebou a spojují se v pediplény. Časté jsou údolní pedimenty. Méně rozšířené erozní glacisy se vyvinuly v méně odolných horninách při úpatí svahů tvořených odolnějšími horninami. V mapě je uvedeno 43 lokalit erozních glacisů.

Na mírně ukloněných vrstvách skalního podloží se nacházejí strukturně denudační hřbety, které zabírají plochu 1 317,3 km^2 (1,67 % státního území) a mají v polygonové a lineární vrstvě délku 1 184,6 km. U 103 lokalit nesouměrných hřbetů (kuest) zabírají příkré čelní erozní svahy plochu 72,2 km^2 (0,09 %) a mají v polygonové a lineární vrstvě délku 376,9 km. Mírné týlové svahy kuest zabírají plochu 588,4 km^2 (0,09 % státního území). V mapě se rovněž nachází 43 erozních glacisů zabírajících plochu 415,2 km^2 (0,53 % plochy státu). Čtvrtohorního stáří jsou kryopedimenty, které se vyvíjely v chladných obdobích pleistocénu v přítomnosti permafrostu. V mapě se nachází 121 kryopedimentů většího rozsahu, které zabírají plochu 2 071,0 km^2 (2,63 % povrchu státu).

Z pseudokrasových erozně-denudačních tvarů zabírají největší plochu pseudokrasová skalní města, a to 16 skalních měst v polygonové vrstvě (plocha 302,7 km^2, 0,38 % území státu) a 21 lokalit v bodové vrstvě.

Z akumulačních tvarů georeliéfu Česka zaujímají největší plochy povrchy na spraších, zejména ve sníženinách (celkem 6 370,3 km^2, 8,04 % státního území). Tyto povrchy, na kterých se většinou vyvinuly úrodné půdy mají velký hospodářský význam. Následují rovinné povrchy údolních a poříčních niv, které zabírají plochu 3 791,0 km^2, 4,79 % státního území). Značné plochy rovněž zabírají povrchy akumulačních říčních teras (tab. 1), a to 2 688,5 km^2 (3,41 % státního území). Z fluviálních tvarů jsou to dále proluviální roviny (340,0 km^2, 0,43 % státního území) a proluviální náplavové kužely (181,7 km^2, 0,23 % státního území. V oblastech kam zasáhl v pleistocénu pevninský ledovec zabírají největší plochy sandry (51 lokalit, plocha 469,7 km^2, 0,60 % státního území). Z eolických tvarů se v mapě vyskytuje ještě 138 přesypů zabírajících v polygonové vrstvě plochu 10,7 km^2 (0,01 % státního území).

Neotektonické tvary na území republiky se dělí do dvou skupin, a to na kerné a vrásové. Z kerných tvarů bylo na území republiky identifikováno 541 zlomových svahů různé výšky i výraznosti. Z toho je v mapě 461 zlomových svahů vyznačeno plošně a celkově zabírají plochu 907,3 km^2 (1,15 % státního území). Dalších 80 zlomových svahů je vyznačeno lineárními značkami. Celkově délka zlomových svahů činí 2 501,3 km. Z vrásových tvarů jsou v plošné vrstvě 3 lokality svahů antiklinál, zabírajících plochu 90,4 km^2 (0,11 %) a 1 svah synklinály zabírající 30,1 km^2 (0,04 % státního území). V lineární vrstvě jsou vyznačeny osy 21 megaantiklinál (celková délka 378,8 km) a osy 7 megasynklinál (celková délka 342,0 km). Do neovulkanických tvarů tradičně řadíme tvary, které vznikly sopečnou činností v třetihorách a čtvrtohorách. Ve skutečnosti se však vzhledem k rozsáhlému odnosu neovulkanických tvarů většinou jedná o erozně-denudační a exhumované tvary. I přesto tyto tvary jsou důležité z hlediska geomorfodiversity krajiny. V mapě autoři rozlišili 219 neovulkanických kup a kuželů zabírajících plochu 102,0 km^2 (0,13 % státního území). U vypreparovaných subvulkanických těles byla provedena generalizace podle plošné rozlohy (tvary větší než 12 ha).

Autoři měli problémy s mapováním antropogenních tvarů, které se neustále mění. Využili při mapování digitální databázi České geologické služby a aktuální letecké snímky. Vedle kvantitativního hodnocení jednotlivých tvarů a skupin tvarů georeliéfu autoři přistoupili s pomocí plošné vrstvy zmíněné mapy ke kvantitativnímu hodnocení prostorových struktur georeliéfu v prostředí GIS (viz obr. 3, 4 a 5). Práce na geomorfologických mapách pro Atlas krajiny ČR ukázaly, že GIS je důležitým prostředkem geomorfologického výzkumu.

Práce vrcholí hodnocením geomorfodiversity státního území.

Obr. 1 – Výřez z digitální geomorfologické mapy Česka (Demek, Balatka, Kirchner, Mackovčin, Pánek, Slavík 2009)
Obr. 2 – Legenda digitální geomorfologické mapy Česka (Demek, Balatka, Kirchner, Mackovčin, Pánek, Slavík 2009)
Obr. 3 – Rozmístění tříd tvarů georeliéfu na území Česka
Obr. 4 – Hustota tvarů georeliéfu na území Česka
Obr. 5 – Počet genetických tříd tvarů georeliéfu (celková geomorfodiverzita) na území Česka

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