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GEOMORPHOMETRY OF THE PHYSICAL AND GEOGRAPHICAL MICROREGION OF THE POLKOWICE HILLS

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Summary

In this paper, a morphometric analysis of the terrain sculpture was carried out along with the editing of a geomorphometric map of the physical and geographical microregion of the Polkowickie Hills, which so far was not present in the literature for the studied area. The analysis was performed using the GIS program (ESRI ArcMap), which is based on a digital elevation model (LiDAR – DEM). Following primary topographic parameters were selected through digital elevation model processing: aspect, slope, planar curvature, vertical curvature and local height differece, which provide exact information about the variability of the topography and its surface morphological processes. The obtained results of primary parameters allowed for the classification of relief forms in the studied area using the unsupervised ISODATA classification method. The final stage consisted of editing a geomorphometric map of the Polkowickie Hills microregion and a presentation of the distribution of morphometric classes with the height division of boundaries of the obtained geomorphometric separations.

The results of the calculations and analyses allowed for the separation of various areas in the Polkowice Hills, and giving them their own names by the author. The choice of the unsupervised classification method and the independent definition of the number of classes gave positive results of terrain clustering of the studied area. The compliance of the results of the selected classification method with the actual topography (of which the author has extensive field and observational knowledge) confirms the selection of appropriate geomorphometric indicators and the unsupervised classification method, which in the examined case turned out to be computationally effective.

Keywords

geomorphometry • geomorphometric indicators • unsupervised classification • Polkowice Hills • geomorphometric map

1. Introduction

Fundamentally, modern science should determine a coherent structure of the world we are surrounded by. By creating a representation that adequately maps the actual world, it would be possible to analyse it in detail and, above all, to understand and predict the behaviour of the environment. In order to correctly model an element of the real environment, it is necessary to select appropriate parameters for its description. The so called geomorphometric indicators are applied to modelling of the topographic surface of the terrain. Geomorphometry is a branch of science related to quantitative terrain analysis, which is performed by mathematical and IT tools [Olaya 2009]. The basic parameters used in geomorphometry are: slope, aspect and terrain curvature. The variation in height in the vertical and horizontal directions is expressed by the slope and aspect parameters, respectively. The diversity of gradients and exposure is represented by the terrain curvature parameter [Pike et al. 2008]. Determining the indicators is now very simple, even for large areas, due to the widespread use of computer software in the field of geomorphology [Kasprzak and Traczyk 2010]. Today, geomorphometric indicators are determined using Digital Terrain Model (DTM) [Szypuła 2010]. Current methods, especially remote sensing methods, allow to create high-accuracy models for large areas, too [Ewertowski and Rzeszewski 2007].

The purpose of the study is to calculate geomorphometric indicators: gradient, exposure, planar and vertical curvature, and local height difference based on the Digital Elevation Model (DEM) obtained from the LiDAR system for the test area, which is currently most commonly used method for geomorphological research [Zhang et al. 2020]. The next step is the application of the unsupervised classification method, then classifying and naming the topographic forms occurring in the studied area, and analysing the correctness of the classification. On this basis, a geomorphometric map of the Polkowickie Hills microregion was prepared.

2. Research design

In this paper, a simplified model of reality will be submitted to analysis, which will take into account measurable features of topography constituting the terrain sculpture. The source of data for obtaining geomorphometric coefficients and the resulting surface model in the article will be provided by the DEM (Digital Elevation Model), which allow for the presentation of the topography of the area with high accuracy [Lindsay and Dhun 2015].

Correctly determined geomorphometric indicators depend on the source of information, the scale of development, the division of the area into calculated units, surface sampling, as well as the choice of method for determining their features. Taking into account all the relationship between these matters, the choice of one determines the other [Wieczorek and Żyszkowska 2011].

Essentially, the most important in a geomorphometric map is appropriate selection of the accuracy of the source of information (usually the scale of the map) for the size of forms to be analysed and developed. A detailed analysis of the individual terrain forms is therefore carried out, requiring high detail data [Szypuła 2010]. General geomorphometry analyses refer to regional analyses and can be conducted on the basis of less detailed data [Wieczorek and Żyszkowska 2011].

Morphometric features of terrain surfaces are topographic parameters, or quantitative attributes, which indicate the formation of the surface of the terrain [Wood 1996].

They can be calculated directly from the Digital Elevation Model as primary indicators: aspect, slope, or from a secondary model, generated from two or more primary derivatives (topographic wetness index, planar and vertical curvature). Calculations can be made for both local (small) and regional (large) areas [Brzezinka 2017].

The following topographic indicators can be used to explain, model and analyse processes in nature and on the surface of the terrain. In literature there are many attempts to classify areas basing on them [Zhang et al. 2013, Bac-Bronowicz and Grzempowski 2018].

Slope is a basic parameter of the terrain surface. It determines the variability of the height of an analysed surface per unit length in the direction of the steepest slope and is expressed in degrees, percent or radians [Brzezinka 2017].

Aspect characterizes the surface and determines the gradient direction of a slope, which is defined as azimuth, i.e. an angle measured clockwise between the north and the maximum gradient [Urbański 2008]. Aspect can be expressed in degrees or radians. In hydrological and ecological modelling, the maps of the exposure direction of gradients are extremely important as the amount of solar radiation reaching a slope depends on its exposure [Brzezinka 2017].

Curvature describes the shape of a slope, most often with two measures: planar and vertical curvature. The first curve – planar, includes the differentiation of gradients, i.e. the gradient direction of a slope along the contours. It is used to classify topographic forms (valleys, slopes, ridges). It assumes positive values for ridges, and negative for valleys. The vertical curvature relates to the exposure variability, which is the process of changing the gradient along the runoff line. Its significant as it determines the changes in accumulation processes and their speed [Urbański 2008]. It is especially useful in hydrological studies, where vertical curvature is responsible for changes in the runoff speed [Shary et al. 2002]. It adopts positive and negative values for concave and convex slopes, respectively [Brzezinka 2017].

Local height difference is a parameter used to describe the terrain surface. Basically, it describes the altitude variation that occurs in a given area. It shows the difference between the highest and the lowest point of a given area [Giętkowski and Zachwatowicz 2008].

3. Research area

The Polkowice Hills belong to the Dalków Hills mesoregion and the Trzebnica Wall macroregion according to the physical and geographical division [Kondracki 2000, Solon et al. 2018]. They are a group of the Dalków Hills located furthest to the south-east. They stretch from west to east, from the Moskorzynka Valley to Stara Rudna, forming an arc of about 20 kilometres long and 6–8 kilometres wide. The northern slopes of the hills go down to the Grębocice Plain. The eastern border of the described area is marked by the Odra River, which runs along the towns of Lubin, Rokitki and Gromadka. The central part of the Polkowickie Hills has been levelled, because the "Żelazny Most" tailings reservoir was built there. In turn, to the south-east of the

Polkowice town, the elevations of the Polkowickie Hills reach a maximum height of 228 m a.s.l. [Bok 2006].

The area in question is located in the lowlands of central Poland. The topography of these lowlands is characterized by Quaternary backfilling, showing a connection with deeper structures. The area of central Poland's lowlands in south-western Poland adjoins the Sudetes mountain belt, creating lowland areas varied by the Trzebnica Hills, separated by vast depressions, and latitudinal glacial valleys. The Polkowice Hills as components of the Trzebnica Hills are low but very well exposed hills. This is due to the river valleys they adjoin. Such a landscape was formed as a result of glaciation. The formed relief is the result of the accumulative activity of the ice sheet and its waters. The most visible forms are the Central Polish glaciation in the Warta stadial. These forms become a high wall consisting tills, covered with sediments of sand and glacial gravel. In many places the slopes are covered with fertile dust deposits, not only of aeolian origin [Bok 2006].

4. Research methodology

The data required to produce a geomorphometric map is a data set received from (LiDAR) airborne scanning. They were obtained from the Head Office of Geodesy and Cartography in ASCII format. Each dataset is a 1:5 000 scale map sheet of the national geographic coordinate system 1992. This paper uses 128 sheets of data sets with the unit size of one pixel 1 m × 1 m covering the entire area of the Polkowice Hills.

In order to define the boundaries of the analysed area, the physical and geographical division made by Jerzy Kondracki [2000] was used due to the fact that Solon et al. [2018] modified the Kondracki division, and the mesoregion – the Dalków Hills, which includes the studied area – has not changed significantly and has not acquired a new name or division into many units of the same order. The selection of such physiogeographic units allows for the identification of morphological barriers, and significantly increases the reliability of the obtained results, as Bac-Bronowicz and Grzempowski [2018] found in their work on climate modelling. For this purpose, topographic maps on a scale of 1: 10 000 as well as physical and geographical studies from the *Atlas of Lower and Opole Silesia* [2008] were studied. The paper focuses on the analysis of the Polkowickie Hills microregion. The data was created in the ShapeFile format in the national geographic coordinate system 1992.

To present the topography, contour lines were used, interpolated on the topographic map of the national geographic coordinate system 1965 in the scale 1:10 000 and converted to the national geographic coordinate system 1992. The data was saved in ShapeFile format.

The development of the geomorphometric map was based on the DEM and its derivatives, which are geomorphometric indices calculated in the ArcMap program with the use of appropriate tools. *Resampling* was chosen for the research in order to reduce the volume of data and remove measurement noises as well as terrain micro-irregularities that interfere with the calculations. The initial size of pixels was 1 m × 1 m, however after sampling it increased to 5 m × 5 m. The prepared altitude data was subjected to diversification. A 32-bit and unmarked pixel type was adopted for the optimization of further calculations. The generated raster model served as a basis for the calculation of geomorphometric indicators, which are presented later in the paper. Considering the size of the analysed area, the paper presents the results of the calculation of indicators for the selected part of the area graphically (sheet M-33-21-A-c-4). As a result, it was possible to present in detail the received results. The DEM prepared this way (Fig. 1) allowed for the calculation of geomorphometric indicators, which represent important inputs defining the elements of topography needed for further calculations [Klingseisen et al. 2008].

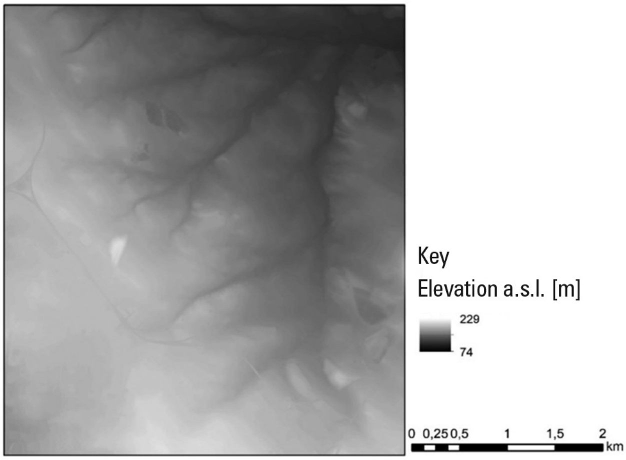

Fig. 1. Altitude raster (sheet M-33-21-A-c-4)

The slope is a direction of slope gradient and is presented by a gradual measure (0–360°) and zones related to the directions of the world. The value –1 is assigned to areas inclined below 1°, indicating flat terrain. The received directions of exposure are presented in Figure 2. In subsequent calculation steps, this parameter is not included in the calculation process, as the insolation of the terrain does not affect its formation. The slope shape is described by curvature, which is represented by two measures – planar and vertical curvature (Fig. 2). With planar curvature, the lines of valleys and ridges can be represented. Vertical curvature, on the other hand, shows concave slopes through positive values, i.e. sites where occurs accumulation. Whereas negative values indicate convex slopes, i.e. sites dominated by erosive processes [Wieczorek and Żyszkowska 2011]. Gradient is another calculated indicator that accepts values from 0 to 43.03 degrees in the studied area (Fig. 3). The calculation of local height difference was also assumed. It is calculated as the difference in pixel height and the smallest height value in the circular vicinity with a radius of 10 pixels (50 m). The obtained values are shown in Figure 3.

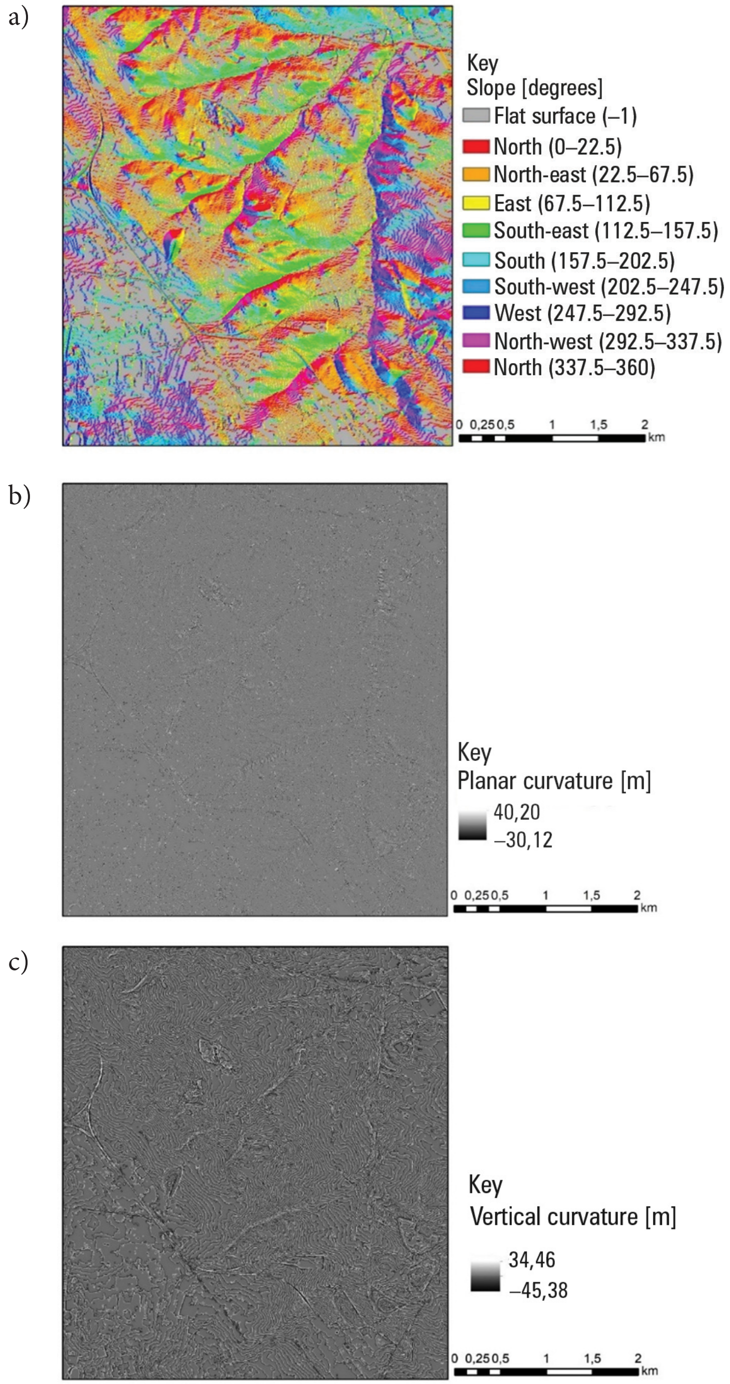

Fig. 2. Raster: aspect (a), planar curvature (b), vertical curvature (c) (sheet M-33-21-A-c-4)

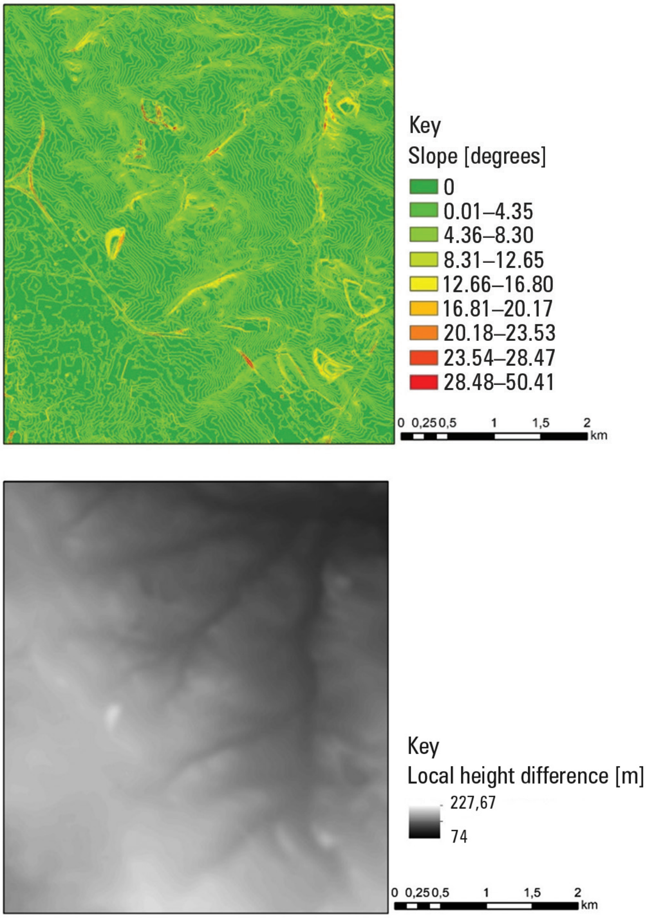

Fig. 3. Raster: slope (a), local height difference (b) (sheet M-33-21-A-c-4)

The values of the indicators have been reclassified to the range 0–255, allowing to create a raster by a tool that uses unsupervised classification. Unsupervised classification is a semi-automated process in which the calculation system relies on pixel analysis from multispectral data (statistical analysis) and searches for similar pixels from each available channel, after which it extracts the number of clusters assumed initially [Singh and Dubey 2012]. In the next section, the user interprets the results independently (based on knowledge of the studied area). She assigns the appropriate clusters to the shape class (geomorphometry) or land use (remote sensing). In this type of classification, there is no need to provide the system with cluster patterns [Będkowski and Adamczyk 2007, MacMillian and Shary 2009].

Based on the results of the unsupervised classification, the terrain sculpture was divided into 6 classes with assigned names. The following are the classes of terrain sculpture with the names:

- flat plain terrain of valley depressions and glacial valleys (I),
- rolling plain terrain (II),
- gentle terrain (slope) of the Polkowice Hills (III),
- moderately gentle terrain (slope) of the Polkowice Hills (IV),
- steep terrain (slope) of the Polkowice Hills (V),
- flattening of the ridges of the tops of the Polkowice Hills together with the Żelazny Most reservoir (VI).

The next step was to determine the exact boundaries between classes, i.e. filtering and removing cell values by assigning them new values in regard to adjacent pixels. The boundaries between classes have been smoothed to achieve final results (Fig. 4). In order to be able to analyse the results in quantitative terms, the obtained results had to be changed from raster to vector file.

The geomorphometric map (Fig. 6) separates 6 classes of terrain sculpture (Fig. 7) (Table 1). The largest share of the area of the Polkowice Hills belongs to class 6, that is, flattening of the ridges of the mounts together with the Żelazny Most reservoir, which accounts for 4.3% of the surface area of the Hills. Classes 3 and 4, i.e. gentle and moderately gentle areas, account respectively for 19% of the area. Class 5 occupies a little less – steep terrain (about 19%). Figure 5 shows the hipsographic colours of the height zones of the individual classes for the Polkowice Hills.

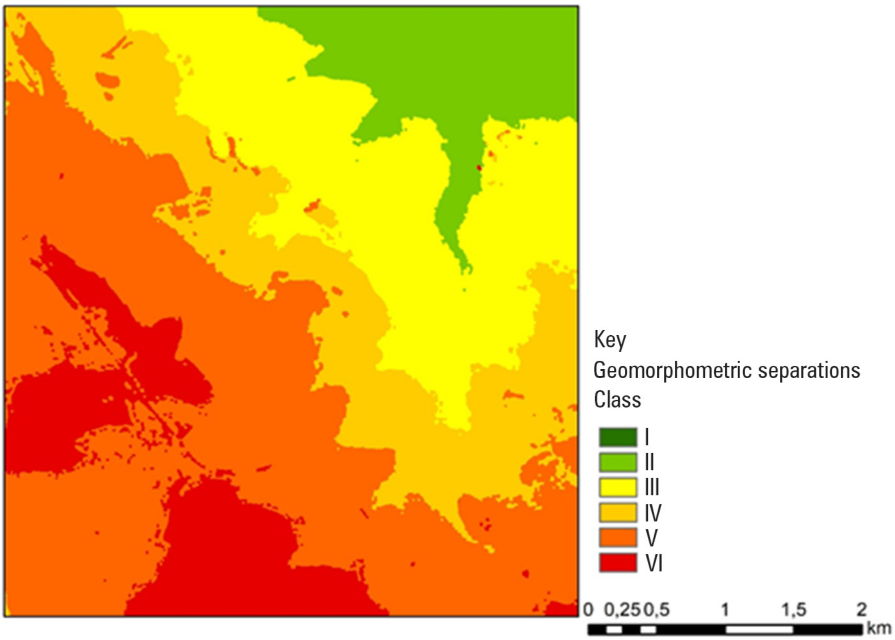

Fig. 4. Geomorphometric separations (sheet M-33-21-A-c-4)

Table 1. Percentage share of morphometric classes on the geomorphometric map of the Polkowice Hills

Class	Area [ha]	Share [%]
I	1 416,20	3,9
II	5 801,12	16,1
III	6 966,07	19,4
IV	6 881,23	19,2
V	6 813,03	19,0
VI	8 033,09	22,4
Sum	35 910,74	100

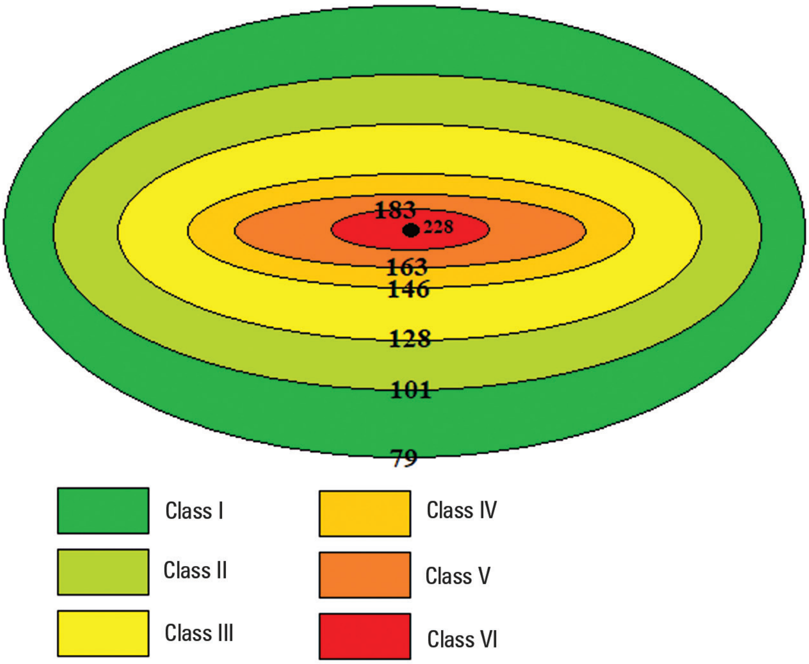

Fig. 5. Altitude distribution of geomorphometric separation limits in m a.s.l.

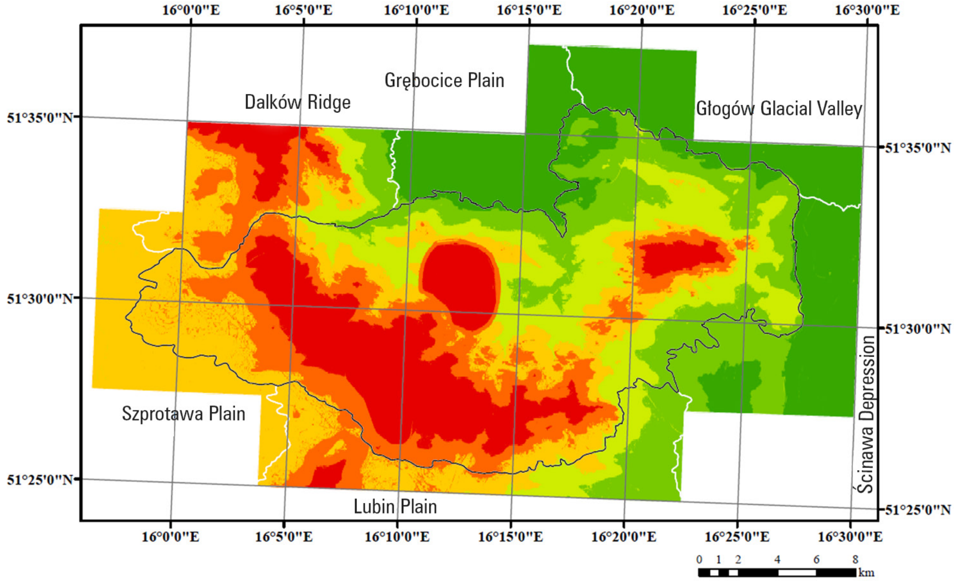

Fig. 6. Geomorphometric map of the physical and geographical microregion of the Polkowice Hills

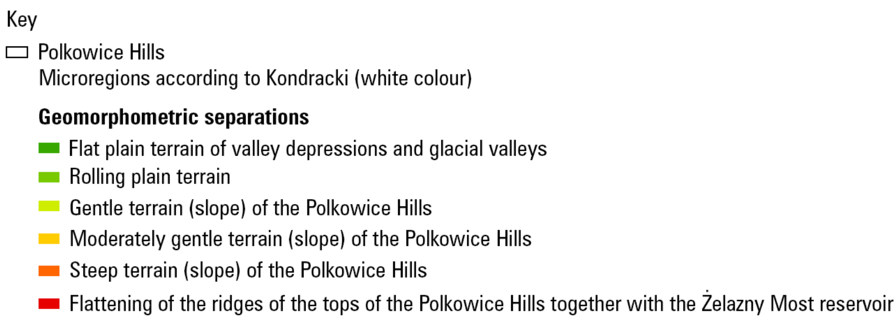

Fig. 7. Key to the geomorphometric map of the physical and geographical microregion of the Polkowice Hills

5. Summary and conclusions

The research was based on the analysis of a geomorphometric map of the Polkowice Hills. With DEM it is possible to calculate geomorphometric indicators, i.e. slope, aspect, planar and vertical curvature, and height difference. They provide a basis for the development and presentation of the variability of the terrain sculpture. The accuracy of the input data has a definite impact on the results. Creating geomorphometric indicators requires primary focus on the input. The quality of data should be chosen in such a way as to ensure the correct determination of the indicators, for which reason LiDAR images have been used. However, their high accuracy does not eliminate erroneous indicator values. Such errors can be observed, for example, in agricultural land areas, when arable furrows distort the ground during aerial laser scanning, and it was therefore decided to change the size of the calculation raster. For the research in this paper, the method of classification of unsupervised ISODATA was selected due to its arbitrariness compared to the method of geomorphones and TPI (topographic position index), where the decision-making process of naming forms of terrain sculpture as presented by Weiss (2001) created classes by combining clusters in relation to each other, and these classes were assigned a specific name of the geomorphometric form. Therefore, positive results were obtained using the unsupervised classification method. This geomorphometric map presents the author's names of the terrain sculpture of the Polkowice Hills, which until now have not been described in this way in literature.

In conclusion, the editing of the geomorphometric map was successful. The data shown on the map fully reflect reality. As a result of the editorial processes carried out, it is stated that the map is a source of valuable knowledge about the geomorphological forms of the Polkowice Hills. It is not only a valuable map base, but also a numerical base that can be developed in the future.

References

Bac-Bronowicz J., Grzempowski P. 2018. Regionalization of geographical space according to selected topographic factors in reference to spatial distribution of precipitation: Application of artificial neural networks in GIS. Environ. Earth Sci., 77, 1–17.

Będkowski K., Adamczyk J. 2007. Digital methods in remote sensing. SGGW, Warsaw.

Bok A. 2006. "Dalkowskie Hills" Union of Municipalities of the Copper Basin. Nature and tourism guide. Polkowice.

Brzezinka M. 2017. Application of GIS in hydrological modelling.

Ewertowski M., Rzeszewski M. 2007. Numerical Terrain Models. Paper presented at GIS Day. Poznań.

Giętkowski T., Zachwatowicz M. 2008. Classification of relief based on Numerical Elevation Model derivatives and its potential applications in landscape studies. Problems of Landscape Ecology, 21, 111–125.

Kasprzak M., Traczyk A. 2010. Geomorphometry of the granite part of the Karkonosze. Landform Analysis, 13, 33–46.

Klingseisen B., Metternicht G., Paulus G. 2008. Geomorphometric landscape analysis using a semi-automated GIS-approach. Environ. Modell. Softw., 23, 109–121.

Kondracki J. 2000. Polish regional geography (Regional Geography of Poland). PWN, Warsaw.

Lindsay J.B., Dhun K. 2015. Modelling surface drainage patterns in altered landscapes using LiDAR. Int. J. Geogr. Inf. Sci.

MacMillan R.A., Shary P.A. 2009. Landforms and Landform Elements in Geomorphometry. Geomorphometry – Concepts, Software, Applications. Elsevier, Amsterdam, The Netherlands, Chapter 9, 227–254.

Olaya V. 2009. Basic Land-Surface Parameters. Geomorphometry – Concepts, Software, Applications. Elsevier, Amsterdam, The Netherlands, Chapter 6, 141–169.

Pawlak W., Anioł-Kwiatkowska J., Pawlak J., Nowak-Ferdhus E., Migoń P., Malicka A., Marciniak A., Źak W. 2008. Atlas of Lower and Opole Silesia. In: Collection of maps, University of Wrocław, Polish Academy of Sciences – Branch in Wrocław, printed maps.

Pike R.J., Evans I.S., Hengl T. 2008. Geomorphometry: a Brief. In: T. Hengl, H.I. Reuter (eds.). Developments in Soil Science, vol. 33. Geomorphometry: Concepts, Software, Applications. Elsevier, 1–28.

Shary P., Sharaya L., Mitusov A. 2002. Fundamental quantitative methods of land surface analysis. Geoderma, 107(1–2), 1–32.

Singh V., Dubey A. 2012. Land Use Mapping Using Remote Sensing & GIS Techniques in Naina-Gorma Basin, Part of Rewa District, M.P., India. International Journal of Emerging Technology and Advanced Engineering, Allahab, 151–156.

Solon J., Borzyszkowski J., Bidłasik M., Richling A., Badora K., Balon J., Brzezińska-Wójcik T., Chabudziński Ł., Dobrowolski R., Grzegorczyk I., Jodłowski M., Kistowski M., Kot R., Krąż P., Lechnio J., Macias A., Majchrowska A., Malinowska E., Migoń P., Myga-Piątek U., Nita J., Papińska E., Rodzik J., Strzyż M., Terpiłowski S., Ziaja W. 2018. Physico-geographical mesoregions of Poland: Verification and adjustment of boundaries on the basis of contemporary spatial data. Geographia Polonica, 91(2), 143–170.

Szypuła B. 2010. Digital terrain models as the main data source in geomorphometry. In: W. Żyszkowska, W. Spallek (eds.), Numerical terrain models in cartography. University of Wrocław IGiRR, Department of Cartography, Wrocław, 110–121.

Urbański J. 2008. GIS in natural science research. Wydawnictwo Uniwersytetu Gdańskiego, Gdańsk.

Weiss A. 2001. Topographic Position and Landform Analysis. Poster presentation. ESRI User Conference, San Diego.

Wieczorek M., Żyszkowska W. 2011. Geomorphometry – morphometric parameters in relief characterisation. Polish Cartographic Review, 43, 130–144.

Wood J. 1996. The Geomorphological Characterisation of Digital Elevation Models (doctoral thesis).

Zhang B., Fan Z., Du Z., Zehng J., Luo J., Wang N., Wang Q. 2020. A Geomorphological Regionalization using the Upscaled DEM: The Beijing-Tianjin-Hebei Area, China Case Study. Sci. Rep., 10, 10532.

Zhang Z., Gang H., Ni J. 2013. Effects of topographical and edaphic factors on the distribution of plant communities in two subtropical karst forests, southwestern China. J. Mt. Sci., 10(1), 95–104.

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