APPLICATION OF FREE OPEN-SOURCE SOFTWARE TOOLS TO AUTOMATIC AND SEMIAUTOMATIC CLASSIFICATION OF LANDFORMS IN LOWLAND AREAS

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Modern relief of lowland areas covered by Pleistocene glaciations was formed by accumulation, erosion and deformation action of ice-sheets, because of denudation processes in periglacial environment and interglacial (postglacial) and Holocene action of rivers and wind. The relief created this way distinguishes considerable variety of landforms but small diversity in relative heights. Commonly used for upland areas landforms classification methods can not be uncritically imported.

The aim of this research is to implement selected application GIS Free Open Source Software G: Grass, R, and TAS to automatic and semiautomatic classifications of landforms on lowland areas and to compare results applying in older geomorphologic-cartographic studies.

Classification have been made on digital elevation model of area 42 x 25 km with resolution of 5 metres for raster cell.

The surface of the trend of the drainage network beginning was determined using the Local Polynomial Regression Fitting procedure from the *stats* package of the R language with the smoothing out parameter 0,3, that was set experimentally. Relative altitude was received by subtracting from the original surface the surface of the trend of the drainage network beginning.

Key words: geomorphometry, GIS, DEM, Grass, R, TAS, Pleistocene glaciations

INTRODUCTION

During recent 15 years there has been an increasing interest in developing generic procedures for the automatic landscapes classification in order to define the effective management units for precise landforms analysis in regional and local scales. Nowadays researching tends to have current, manual procedures for setting and describing morphological and pedological units replaced with repetitive, effective, automatic and semiautomatic methods. There is a problem with standardization of landform elements classification that could be automatically used for wide range of landforms (MacMILLAN et al. 2000).

In classifications that have been applied so far various topographical derivatives were used. Those classifications were worked out for the uplands whereas a considerable part of the land areas consists of the lowlands. In spite of not great the relative heights diversity these areas are particularly abundant in landforms. On the European Lowland these landforms are connected mainly with the presence of the continental ice-sheets – glacial and fluvioglacial forms as well as the younger periglacial and Holocene ones (which are the result of an Aeolian activity). The authors have noticed a need to create a method of the area landforms classification on the areas of slight differences in height, including the lowlands most of all.

There are several methods of the area landforms classification. Marking off the landforms with the determined genesis is the most widespread one so far (the genetic classification) and is applied in order to draw up the geomorphological maps (KRYGOWSKI 1961, BARTKOWSKI 1963 and others). The nongenetic classifications are based on geometry of the elementary forms such as the morphological diversification of slopes for instance (MAXWELL 1870, EVANS 1980, DIKAU 1989, PIKE 1995, IRVIN et al. 1997, DRĂGUȚ and BLASCHKE 2006) or the areas classification as regards the relief character proposed by HAMMOND (1964). Prevailing for the research area are the classifications based on the forms genesis that is the geomorphological maps. There is a lack of morphometrical analyses.

Humboldt was one of the first to define the term “geomorphometry” (morphometry) (1849) (after DIKAU et al. 1995) as “the characterization of landforms by the qualitative descriptions of the Earth surface shape and by the quantitative measurements of the ‘physical constitution’ of the Earth surface”.

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So far the automatic and semiautomatic procedures of the landforms classifications have been established for the highland and mountain areas i.e. the areas characterized by the significant differences of the relative height, the large space of the inclined lands – slopes and the significant values of their inclination angles. The landform classification has been based predominantly on the absolute and relative heights differences as well as on the analysis of the slopes geometry – their inclination angle, the development of the profile and plane (PIKE and ROZEMA 1975, PIKE 1995, DIKAU et al. 1995, DRĂGUŢ and BLASCHKE 2006, SHARY 1995 and 2006, TROEH 1964, SHARY and SHARAYA 2006, EVANS 1972 and 1980 and others). Part of these analyses refers to the classifications established earlier. The landform classification of the New Mexico state in the USA may be an example based on the classification of HAMMOND (1964) referring to the relief character (DIKAU et al. 1995).

The algorithms applied to the automatic classification have the task of exchanging the height values for the quantitative, numerical data. There are the following universally used topographical variables and indicators: gradient of slope, profile and plan curvatures, slope aspect, solar illumination, wetness index as well as compound topographical index, slope position and slope length. Introducing the additional variable such as likelihood of inundation by ponding is essential for areas of poorly developed drainage network (MacMILLAN et al. 2000). Most of the algorithms according to MacMILLAN et al. (2000) are used for calculating the universally applied terrain variables such as the slope gradient, slope aspect or plan and profile curvatures. More contextual landform attributes are also applied and they contain the absolute and relative height, the slope length and the relative slope position as well as relative drainage condition or wetness index and average incoming solar energy.

There is an scope of articles presenting the list of methods mentioned above, therefore we refer to the previous publications: PIKE (1995 and 2000), GUTH (1995), NOGAMI (1995), DIKAU et al. (1995), EVANS and McCLEAN (1995), DRĂGUT and BLASCHKE (2006), SHARY et al. (2002), JONES (2002), SHARY (2006), NAPIERALSKI et al. (2007), MacMILLAN et al. (2000) and others.

Many of the applied methods used to concentrate on the detailed analysis of the individual relief components, the slopes first of all. The suggestion of DIKAU (1989) or the modification of DRĂGUŢ and BLASCHKE (2006) or quoted by SHARY et al. (2002) the slopes classifications proposed by TROEH (1964) functioned at areas where the slopes are distinct, of high altitudes and covering a considerable surface of the studied territories.

Referring to these suggestions on lowlands is unreasonable.

The article presents the attempts to classify the landforms of the lowland areas by applying the automatic and semiautomatic methods.

RESEARCH AREA

The research area, a fragment of the Lubska Height, covers the last Scandinavian ice-sheet marginal zone, its hinterland and foreland – the relief of different age and changed by late glacial and Holocene periglacial processes. It is located between the Bóbr River Valley (Dolina Bobru) to the east, the Głogów-Baruth Pradolina (Pradolina Głogowsko-Barucka) to the south, the stretch of the Gubin Hills (Wzgórza Gubińskie) to the north and the Neisse River Valley (Dolina Nysy Łużyckiej) to the west (**Fig. 1**). The genesis of most landforms occurring on that particular area has not been unambiguously determined yet. Big forms such as the Bobrowice Outliers (Ostańce Bobrowickie), the Brody-Drewitz Rampart (Wał Brody-Drewitz) are the erosion remnants, dead-ice moraines or polygenetic forms. Smaller hummocks are predominantly oval kames or elongated eskers. BARTKOWSKI (1963) called for such genesis of most of the forms, reconstructing on the examined area the deglaciation areal type which is prevailing up till now. The negative landforms are the river valleys or the marginal channels (BARTKOWSKI 1963).

The earlier geomorphological analyses of the studied area (TIETZE 1911, KRYGOWSKI 1961, BARTKOWSKI 1963, BARTCZAK 2001a, b, 2003 and CHMAL 2002a, b) are mainly the allocations based on the geological structure and a given landform origin. Apart from that the classifications mentioned above differ about the number of the determined forms and their limit.

That is why the forms allocations based on the undefined origin are open to doubt. The researches aimed at specifying the details of the information concerning the origin of the forms as well as the last Scandinavian ice-sheet limit are conducted on the analysed area. The semiautomatic classification of the area landforms is to be helpful in the analytical process.

Classification have been made on digital elevation model of area 42 x 25 km with resolution of 5 metres for raster cell (8400 x 5000 cells for whole area). The model was gained as a result of manual digitalization of 25 topographic map sheets in scale 1:10 000, with contour

Fig. 1. Digital elevation model was done on the basis of 25 sheets of hypsometric map in scale of 1:10 000

interval of 1,25 meter. The DTM was produced with TopoToRaster ArcGIS module. (AnuDEM – HUTCHINSON 1989).

THE PROBLEM

The aim of this work is an attempt at applying the automatic and semiautomatic classification methods for the lowland areas of the postglacial zone with the usage of local morphometrical variables with following GIS application: GRASS (GRASS DEVELOPMENT TEAM 2009, MITÁŠOVÁ and NETELER 2008), R (R DEVELOPMENT CORE TEAM 2009) and TAS GIS (LINDSAY et al. 2006).

In our opinion the classification methods elaborated for highland areas cannot be directly used for the lowland ones. There is a need to elaborate different principles of classifications. This has been a demand so far (NAPIERALSKI et al. 2007).

One might repeat after MacMILLAN et al. (2000) "how to produce a generic classification of landforms elements that can be applied automatically and virtually without alternation to a wide variety of landscapes".

In the analysis based on the allocated objects the most essential (basic) problem is the criterion on the basis of which the objects are allocated. In literature several suggestions of the objects allocation can be found. DIKAU (1989) worked out a method of allocating the plateaux, convex scarps, straight front, slopes, concave foot-slopes, scarp forelands, cuesta scarps, valleys and small drainage ways as well as crests. Most of these object allocations results from the significant variety of the studied area – considerable height differences, distinct slopes.

The researched lowland area subjected to the analysis is characterized by small height differences. That difference, between the highest situated point (around 140 metres above sea level), which is in the south-eastern part of the examined area, and the lowest situated one (around 44 metres above sea level) in the north-western part of the area amounts to not quite 100 metres (**Fig. 1**). Generally a common tendency can be noticed for the relative height decrease from the southern east (the Żary High Plain – Wysoczyzna Żarska) to the northern west – the Lubsza River Valley and the Neisse River Valley junction.

The numerical analyses in the glacial geomorphology may add new information about the patterns of landforms topological relations, what in connection with the geological data will facilitate the concluding about the palaeogeographical origin and development of the landforms and relief (NAPIERALSKI et al. 2007).

Using in the lowland landforms analysis the methods previously worked out for the highland areas is pointless. It is impossible to use the systems based on the slopes classifications only. In the analysis of the lowland area landforms two basic problems emerge: landforms are distinguished by small differences in relative height (on the research area the difference is 100 metres on the distance over 30 kilometres). And slopes with the inclination over 2º constitute only 2 % of the research area and mark out narrow edges.

Despite the fact, the lowland areas have rich range of forms that are poor perceptible with methods used for the highlands.

METHODS

The relief analysis was carried out basing on 25 sheets of the hypsometric maps at a scale of 1:10 000 with the isoline interval of 1,25 metres which were digitalized manually (**Fig. 1**). The area lying to the west of the river Neisse (the German territory) was analysed basing on the maps at a scale of 1:50 000. On their basis the digital terrain model (DTM) has been prepared with the surface area of 42x25 km and the definition of 5 metres (8400 x 5000 raster cells) by means of the ArcGIS programme.

The classifications based on the basic relief derivatives (slope, aspect, curvatures) did not lead to the satisfactory findings. Therefore as the criterion determining the individual landforms the following have been accepted: the area ordinate relative to the trend surface of the drainage network beginning, the local ordinate diversification (slopes inclination, height and entropy diversification, curvatures system, channels according to the definition of WOOD (1996), and wetness index.

The base surface – surface of the local hydrological trend (**Fig. 2**) – has been outlined basing on the starting points of the drainage network. The flow directions have been determined by means of the D8 algorithm (TARBOTON et al. 1992), thereafter the network has been established with the use of algorithm of O'CALLAGHAN and MARK (1984). This method allows of the mapping out the regular points grid as the OM algorithm determines the starting points of the drainage network on the basis of the identical surface of the dewatered area irrespective of the local relief diversification. The distribution of the drainage network starting points is random. The trend surface of the drainage network beginning has been outlined by means of the LOESS procedure from the *stats* library of the programme R (Local Polynominal Regression Fitting; CLEVELAND et al. 1992 and CLEVELAND 1979) with the smoothing parameter 0,3 that was determined experimentally. The relative ordinate was obtained by taking the trend surface away from the original surface.

Slopes classified on areas of an inclination above 1,7 degrees were subjected to analysis. These areas were extracted using r.param. scale module of GRASS programme. The local height diversification was calculated by means of the r. neighbour module with minimum and maximum values within 180 m radius (**Fig. 4**). Recesses map has been prepared with the use of maximum curvatures (r. param.scale module) with the threshold value of 0,7/ m. Channels (from the perspective of WOOD 1996), ridges, peaks and pits were identified by means of r.param.scale module. Only channels were chosen for the analysis.

RESULTS AND DISSCUSION

The basic assumption of the conducted researches was testing whether the automatic classifications may be applied to the lowland areas. One of the unsupervised classification methods has been used with the help of the "clara" (modified K-means) procedure from the cluster package (PISON et al. 1999). Thanks to that seven morphometric levels have been marked out. The escarpment areas of the inclination over 4 degrees as well as holes without drainage and flat areas of the valley-bottoms described by the maximum values of the wetness index have been put on the level map prepared that way. With the application of

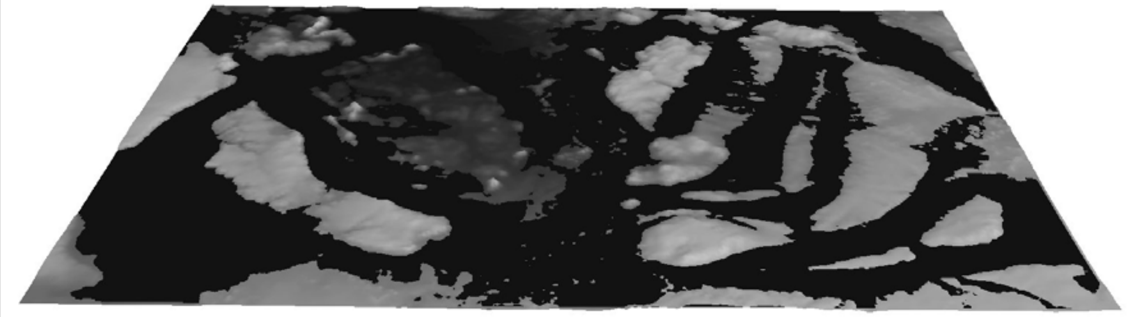

Fig. 2 Nonparametric surface of trend LOESS (CLEVELAND 1979)

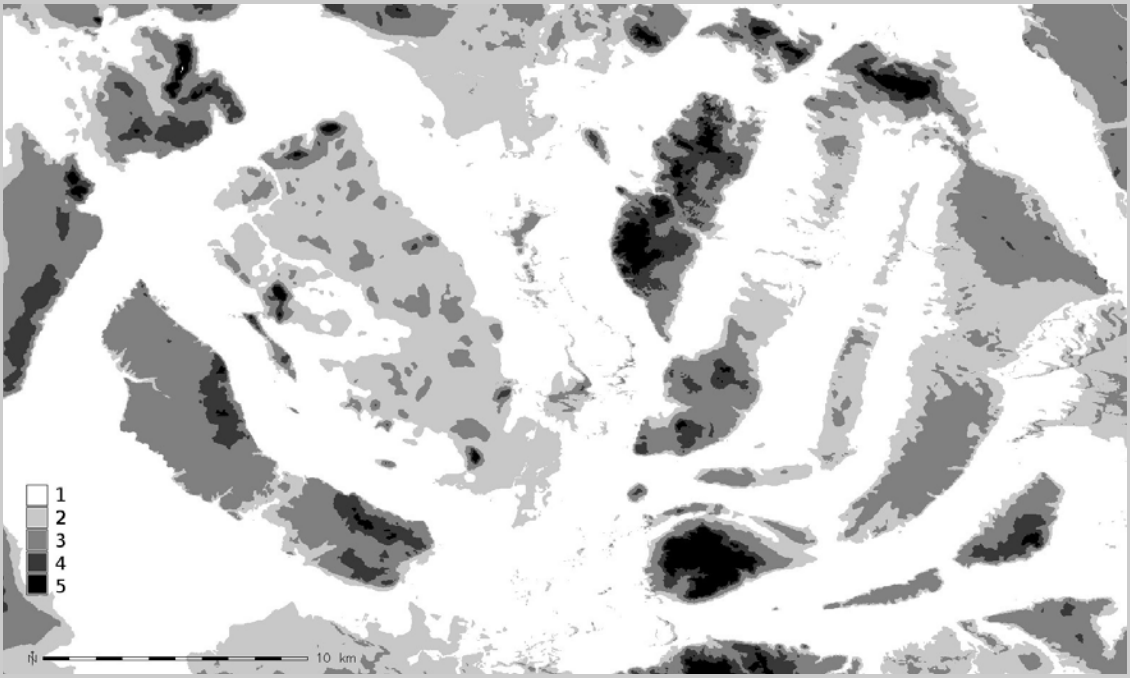

Fig. 3 Morphometric levels classification according to FISHER method (BIVAND 2008)

the absolute ordinates the main tendency of the research area inclination from the southern east to the northern west was marked first of all on the obtained picture.

The second applied method of the automatic uncontrolled classification was the method with the application of the Fisher's algorithm from classInt R package (BIVAND 2008). Eight morphometric levels have been obtained and similarly as while using the “clara” algorithm the absolute ordinate was a differentiating component. The ordinates distribution is polymodal. In order to eliminate the influence of the absolute ordinates on the classification the steps were taken, aimed at the base surface creation regarding which the allocations would be made.

BASE SURFACE AND MORPHOLOGICAL LEVEL CLASSIFICATION

Having in mind the MacMILLAN et al. (2000) statement that the influence of the relative landform position and its shape on the surface flow and the fluvial accumulation is significant for the analysis of surface features and landforms, the drainage network has been analysed. It was determined by the method of STRAHLER (1952).

The local trend surface of the drainage network beginning refers to the common tendency of the examined area inclination. It goes northwestward from the southern east. It enables to determine objects. Forms situated over the local trend surface have been classified as the uplifts whereas the ones lying at an altitude of the local trend and below it are the lowerings. These objects were obtained by taking the absolute ordinates away from the local trend.

Because the application of the absolute ordinates in the analysis by the Fisher's algorithm turned out to be unsatisfactory, the terrain ordinate relative to the trend surface has been used. Map of eight morphometrical levels has been obtained with three levels situated below the local trend surface illustrating the diversification within valleys (**Fig. 3**), one level (4) corresponding to the local trend surface and four levels situated over the local trend classifying the uplifts. In order to state the legitimateness of determining eight morphometrical levels, the entropy – the relief variety analysis – has been carried out by means of the Grass GIS r. texture module. The obtained result did not prove dividing the areas below the local trend into three morphometrical levels. The entropy thereat is very low, in most cases even equals to zero. The relative differences of an altitude do not exceed 1 metre. That is why these areas were decided to be joined into one morphometrical level situated below the local trend. Similar verification has been carried out for the areas situated above the local trend. In this group two levels were characterized by poor diversification of the relative heights (below 1 metre) hence they have been joined into one. As a result of reclassification the map has been ob-

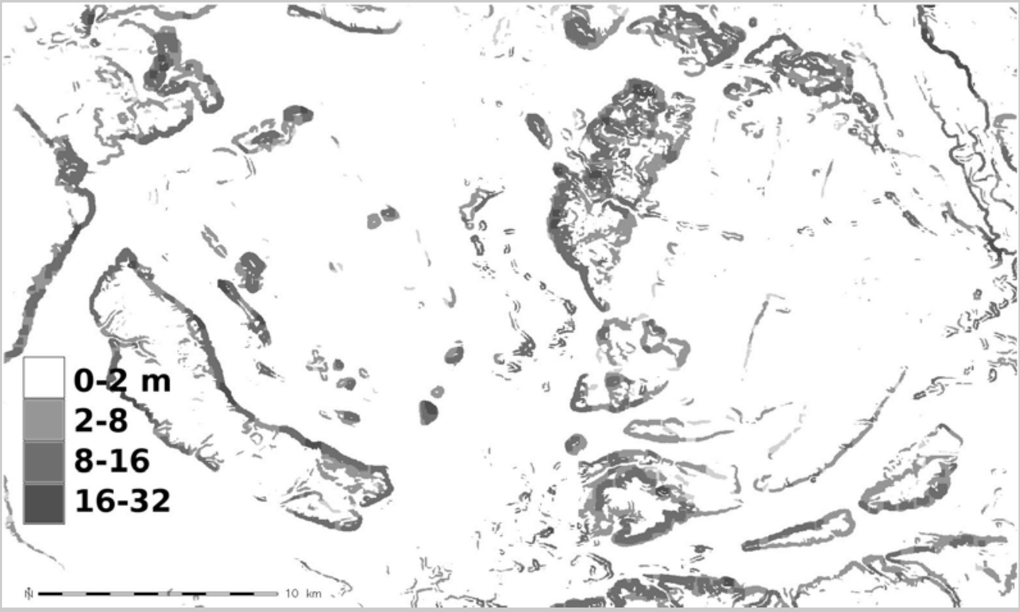

Fig. 4 Classification of slopes on the basis of the height difference. Local diversity of height within a radius of 180 m

tained determining five morphometrical levels: 1 – below the local trend surface, 2 – level of the local trend surface, 3-5 – levels situated above the local trend surface encompassing the plateaued areas and the relic mountains.

CLASSIFICATION OF INCLINED AREAS (SLOPES)

Slopes were the next component to be analysed. Slopes of an inclination angle over 2° constitute less than 10 % of the studied area. Therefore they are not among the relief components helpful to determine objects and analyse them. They are clearly noticeable only in narrow scarp zones. In the course of the slope analysis the problem signalled already by GUTH (1995) or SHARY et al. (2002) emerged, namely the lowering of the slopes inclination angle value in degrees together with the decrease in resolution. The slopes classification for different resolutions has been carried out for the part of an area with the scarp zone distinctly marked. At the resolution change from 5 metres to 50 values for the slopes with a big inclination angle dropped by half. For the slo-

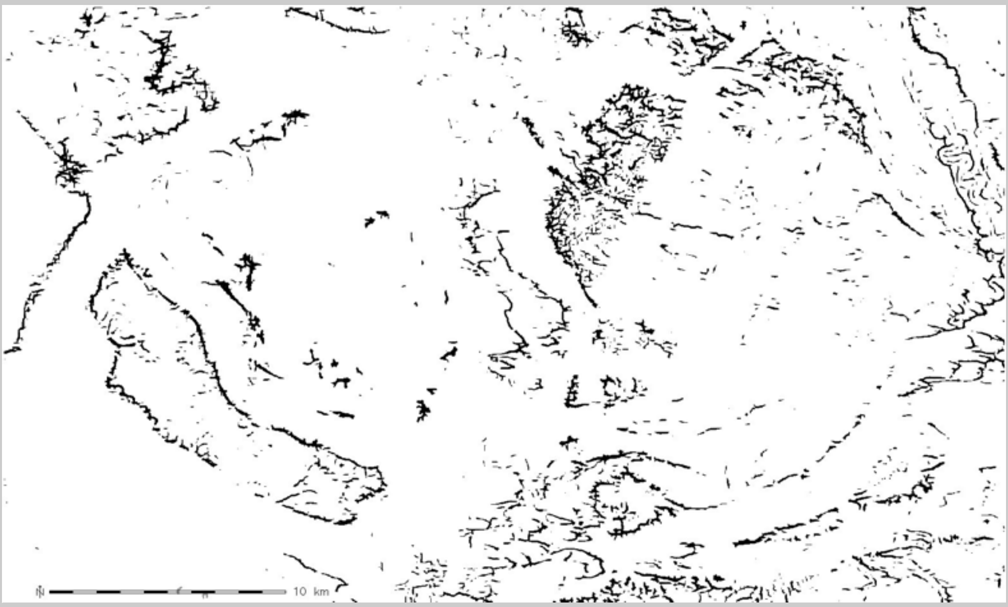

Fig. 5 Edges and slope bending

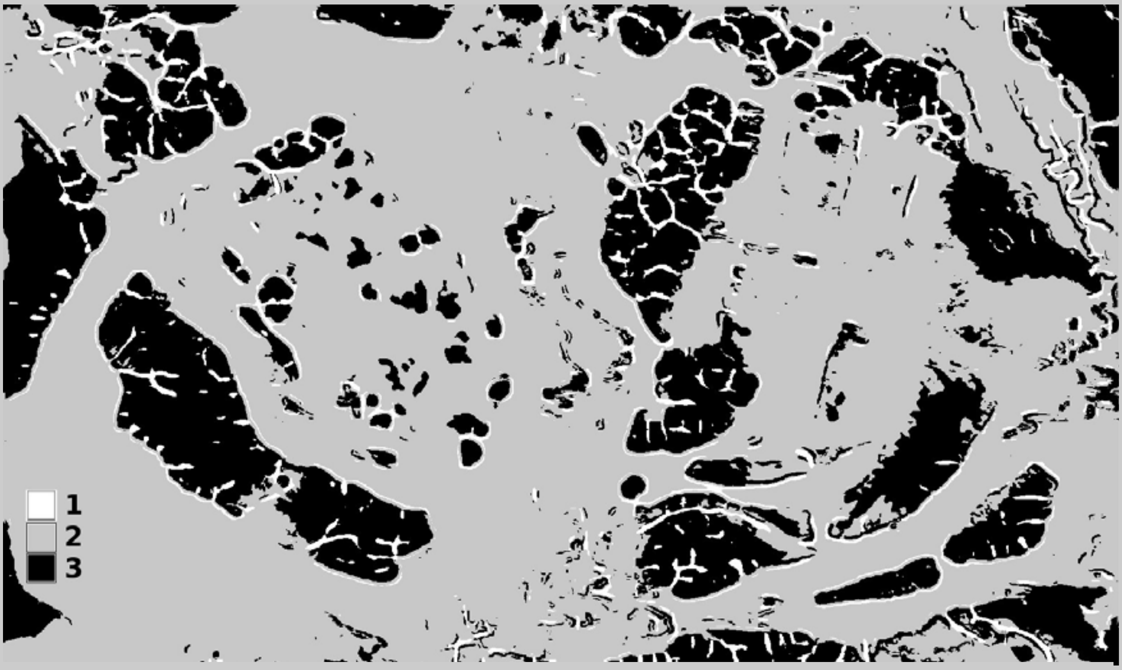

Fig. 6 Channels only on elevations. 1 — channels; 2 — the area beneath the trend surface and on the trend elevation; 3 — the area above the trend surface

ping objects there are smaller differences of the inclination angle value. In order to eliminate that inconvenience the slopes classification has been done on the basis of the height difference.

Slopes have been divided into three classes 0 - 8,8 - 16 and 16 - 32 metres of the height diffe-rence (**Fig. 4**). On that basis their analysis on the examined area can be carried out with great accuracy. The obtained map of the classified slopes has been thereafter put on the morphometrical levels map. The classified slopes distinctly highlighted the areas of higher morphometrical levels.

SMALL FORMS: RECESSES AND CHANNELS

Recesses and edges were the next component to be analysed (**Fig. 5**). The recesses map was overlied on the map of the morphometrical levels with the slopes classes. On that map the recesses highlight the upper limits of many landforms such as erosion outliers, draw main axes of dunes and eskers, mark the river valleys edges.

The analysis has been broadened by the basic erosional elements – channels. The map with the channels distribution on the examined area was compared with the map presenting just two morphometrical levels: the areas situated below the local trend surface as well as the local trend surface and the areas above the local trend, that is uplifts. Channels occur only within elevated areas (**Fig. 6**). They do not occur on the trend surface nor on the areas situated lower than the trend surface. It is indicated by small variety of these areas. It confirms also the rightness of marking off only one morphological level within the lowerings.

The channels map has been put on the morphometrical levels map where the slopes and recesses had been already classified (**Fig. 7**). Channels expressed the variety of the escarpment zones relief, plasticizated the local relief variety of some of elevated areas (the outlier of Dąbrowa). The topological relations have been observed – channels occur always below the recesses. The visualization (2,5D) of the selected pieces of the studied area made with GRASS 3D visualization module – NVIZ which made it possible to observe the landforms which on the hypsometric maps were hardly distinguished in the relief. Such element is a cone appearing at the mouth of one of the channels (most probably of the small denudationallly erosional valley) on the slope of the Dłużka erosional outlier.

CONCLUSIONS

The numerical analysis of the lowland areas relief on maps with the resolution over 30 metres/raster cell is pointless. On maps with smaller resolution the values of the slopes inclination angle are understated.

The unsupervised classifications used for the lowland areas show only the absolute ordinate or 1 class of slopes. Still it were the unsupervised classifications that helped find the

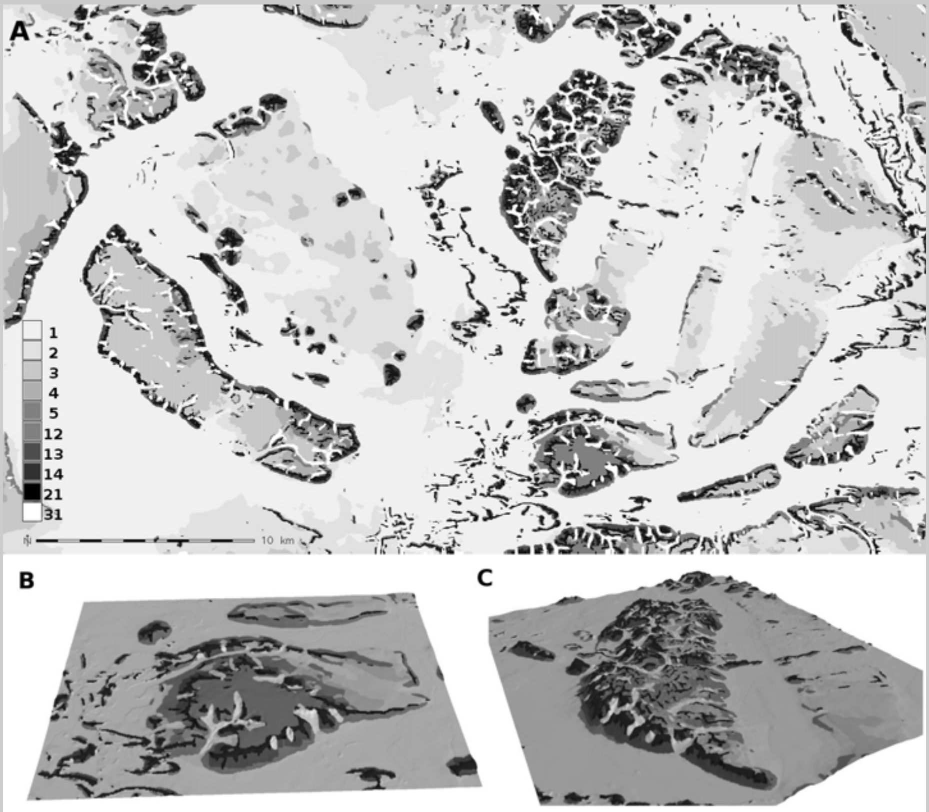

Fig. 7 Classification of landforms: 1 — the area under the trend surface – valley level, 2 — the trend surface, 3 — the area above the trend surface – the lower level of height, 4 — the area above the trend surface – the higher level of height, 5 — the area above the trend surface – the level of outliers, 12 — slopes — height difference 8 m, 13 — slopes — height difference 16 m, 14 — slopes — height difference 32 m, 21 — edges, 31 — channels. Samples of visualizations: B — Dłużek Outlies, C — Dąbrowa Outlier

main parameter differentiating the lowland areas relief, namely the relative ordinate.

Defining the base surface is of the utmost importance in the relief analysis. In this case it was the local trend surface of the drainage network beginning. Single non-parametrical trend (LOESS) has been substituted for the complicated system of the ordinates localization proposed by MacMILLAN et al. (2000) on the polygenetic areas.

Presented method enables to find out most of basic forms as well as bigger entireties.

The basic forms allocations, the recesses for example, offer the possibility of analysing the geometrical forms features (eg. longer axes orientation); channels (watercourses) occur only on the uplifted areas, below the recesses.

Results of the model researches have been confirmed by the field researches and make the interpretation easier.

The allocated elementary forms may be the basis for further topological analysis (the analysis of interrelation between the relief components).

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