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ASSESSING THE APPLICABILITY OF EU-DEM DATASET TO LANDFORM CLASSIFICATION USING THE GEOMORPHONS APPROACH: THE CASE STUDY OF THE EASTERN MECSEK MOUNTAINS REGION

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Assessing the applicability of EU-DEM dataset to landform classification using the geomorphons approach: the case study of the eastern Mecsek mountains region

Abstract: The availability of global coverage digital surface models (like ASTER GDEM or SRTM) and the variation of fused models based on these (like EU-DEM) still has a great impact on scientific researches, as it provides a fairly good base dataset with a low production time and expenses. However, validation reports of the initial digital surface models (DSMs) convinced different characteristics and errors, so it is necessary to examine these prior to use. It is more important in the case of the EU-DEM product, because it has been published without a formal validation. The presented research goes further than just identifying the errors, it attempts to moderate or correct the height differences. For this reason altering the false values of the land cover and filtering the occurring noise was implemented. The correction of the model was verified with statistical and visual methods. Using the novel method of geomorphons for landform classification over the low mountainous and piedmont region of the Eastern Mecsek Mountains generated representative results about the possible application of the EU-DEM for geomorphological studies in areas with similar topography.

Keywords: EU-DEM, digital surface model, denoising, geomorphon, piedmont, Eastern Mecsek Mountains

Introduction

In the past decade the general availability of SRTM and ASTER GDEM versions provided public domain digital height datasets[1] for a growing number of earth science studies (Bolch et al., 2005; Bubenzer and Bolten, 2008; Drăguţ and Eisank, 2012; Gichamo et al., 2012; Grohmann and Sawakuchi, 2013; Seres and Dobos, 2010; Siart et al., 2009). The models became potential data sources for geomorphological researches due to the reasonable information content about the surface topography and acceptable spatial resolution, although multistep pre-processing work might be necessary (Guth, 2010; Hengl and Reuter, 2011).

After the acquired data was distributed, several attempts were made to create a fused digital surface model (DSM) product in order to improve the reliability and applicability of the model, by taking advantage of the complementary nature of the optical and radar remote sensing technologies (Kääb, 2005; Karkee et al., 2008; Robinson et al., 2014). Recently, a continent-wide fusion dataset was published, only for the European Union, called EU-DEM (EU-DEM, 2014a, b; Bashfield and

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[1] The SRTM, ASTER GDEM and EU-DEM datasets are considered as digital surface models, meaning they are not providing elevation data of the bare surface – as digital elevation models – but showing the heights of land cover elements also. However DSM and DEM are not distinguished precisely in these models, as they include the height of the vegetation and buildings, but the resolution is much larger than the size of these surface elements.

Keim, 2011; Frey and Paul, 2012). Different characteristics of the applied source models and the steps of the data compilation significantly affect the quality of the final DSM product.

GDEM and SRTM versions have been well-studied in different regions of the Earth (e.g. Hirano et al., 2003; Jacobsen and Passini, 2010; Szabó and Szabó, 2010; Szabó et al., 2013; Winkler et al., 2006; Zhao et al., 2011), thus the study's focus is to review the specifications of the EU-DEM over the Eastern Mecsek Mountains and explore its applicability for geomorphological researches. Previous papers reported better results for the SRTM (Frey and Paul, 2012; Suwandana et al., 2012), but the validation report and newer researches convinced the improvements of GDEM V2 (ASTER GDEM Validation Team, 2011; Sadeq et al., 2012; Urai et al., 2012).

Over the past period not only the elevation datasets improved – the new data sources and development of terrain analysing methods proposed novel opportunities for the GIS-based, quantitative analysis of the surface (Griffiths et al., 2011). Within the field of geomorphometry many landform classification methods, semi-automated and automated mapping processes have been developed (Drăguţ and Eisank, 2011; Pike, 2009). The chosen geomorphon method basically differs from the widespread methods, as it overcomes the difficulty of scale-dependency and provides an easily applicable, operational process (Jasiewicz and Stepinski, 2013; Stepinski and Jasiewicz, 2011).

The current study has two major goals. The first one is to explore the characteristics of the EU-DEM height dataset and assess its applicability for landform delineation. The second is to test the novel geomorphometric analysis method, geomorphon, for further applications in low mountainous regions. We assume that the study site is suitable for this kind of research, as it has diverse land cover and morphology, although it is clearly not representative for heterogeneous macroregions.

1. Study area

The study is carried out on a 350 km^2 large part of the Eastern Mecsek Mountains and its southern foreland, located between 46.06°, 18.29° (SW), 46.29°, 18.46° (NE) geographic coordinates (Fig. 1). Geomorphological, the area is divided into a low mountainous and a piedmont region, the elevation ranges from approx. 139 m up to 682 at Zengő as the highest peak. The northern part of the study area is dominated by radial horst ranges chiefly built up from Mesozoic limestone and it has been dissected by a complex valley network. However, the southern piedmont region is characterized by fragmented, lowering hills covered with diluvial sediments and loess (Ádám et al., 1990; Lovász, ed., 1977; Pécsi, 1963).

The land cover follows the elevation: as a result of the strict protection of the nature reserves and Natura 2000 areas a wide forested region of about 145 km^2 is present over the mountainous part of the study site, while the piedmont region is mainly covered by extensive agricultural fields. The forests are important for the study as they significantly modify the height values of the DSM, while the category of bare surfaces is important as the representation of real elevations.

2. Methods and materials

2.1 Steps of the quality assessment

The components are organized into a flow chart for a better perspicuity, as the quality assessment process and the attempted error correction consist of several steps (Fig. 2).

During the pre-processing the EU-DEM and the reference datasets were converted to a common projection (Hungarian Unified National Projection [EOV], using bicubic method to create floating values) and cell size, the horizontal misfit of the DSM (ASTER GDEM Validation Team, 2011; Frey and Paul, 2012) was corrected[2] based on the peaks of the Eastern Mecsek Mountains and the cells of mineral extraction sites were re-interpolated by the fill-nulls tool to avoid their misleading errors.

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[2] The coordinates of the three highest peaks in the study area were extracted from the EU-DEM and the reference DEMs and the dislocation values were calculated. Knowing the exact distance in the x and y directions the original coordinates in the header file of the raster map were modified.

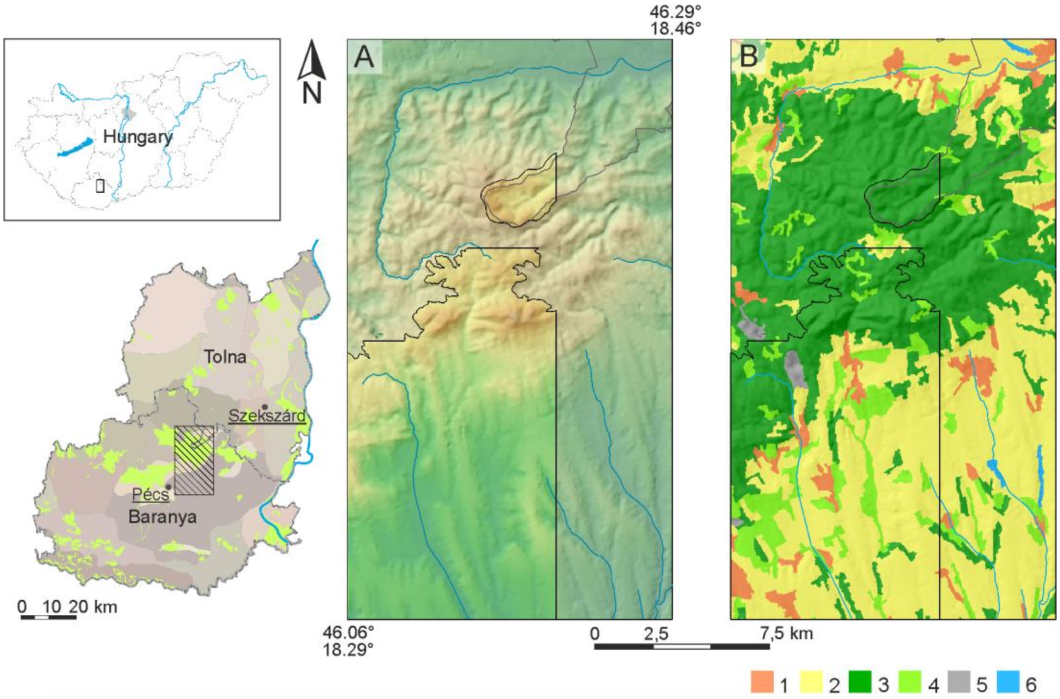

Fig. 1 Location of the study area (also showing the boundaries of micro regions and Natura 2000 SCI areas), its EU-DEM image (A) overlying highlighted reference DEMs and the aggregated land cover categories of CLC2006 (B) – 1 = urban and associated areas; 2 = areas considered as bare surface; 3 = forests; 4 = areas covered with medium height vegetation; 5 = mineral extractions; 6 = water bodies

The data analysis included computing the effective resolution of the EU-DEM (Guth, 2010), and visualizing the representation of the surface and errors. An important task was the thorough examination of the vertical accuracy. According to Mukherjee et al. (2013) the assessment of models based on a few sample points is not a proper method, thus similar to cited research surface-to-surface comparisons of the satellite based DEMs and the contour-based DEMs were performed and some basic error statistics (root mean square error [RMSE], mean error [ME], mean absolute error [MAE], standard deviation of errors [SD) were calculated. Based on previous studies (Frey and Paul, 2012; Szabó, 2011; Zhao et al., 2011) the correlation of height errors with terrain characteristics and land cover types was assumed and therefore examined. An attempted method was carried out to improve the DSMs. The outstanding errors were corrected (Neteler, 2005) and the whole dataset was modified according to the topography and land cover, in order to make the models more representative regarding the real surface. Finally, a denoising algorithm[3] was implemented (Stevenson et al., 2010; Sun et al., 2007).

Due to the modifications the accuracy of the resulted models needed to be retested. For the validation not only the error statistics were studied, but characteristics of the digital surface – relevant for geomorphological researches – were examined.

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[3] This algorithm can be used separately using the provided executable file or run directly from GRASS as an add-on. To control the smoothing effect two input values are necessary: the threshold that defines the possible sharpness of the preserved forms, and the number of iterations. In this case we chose the values used by the authors for SRTM model.

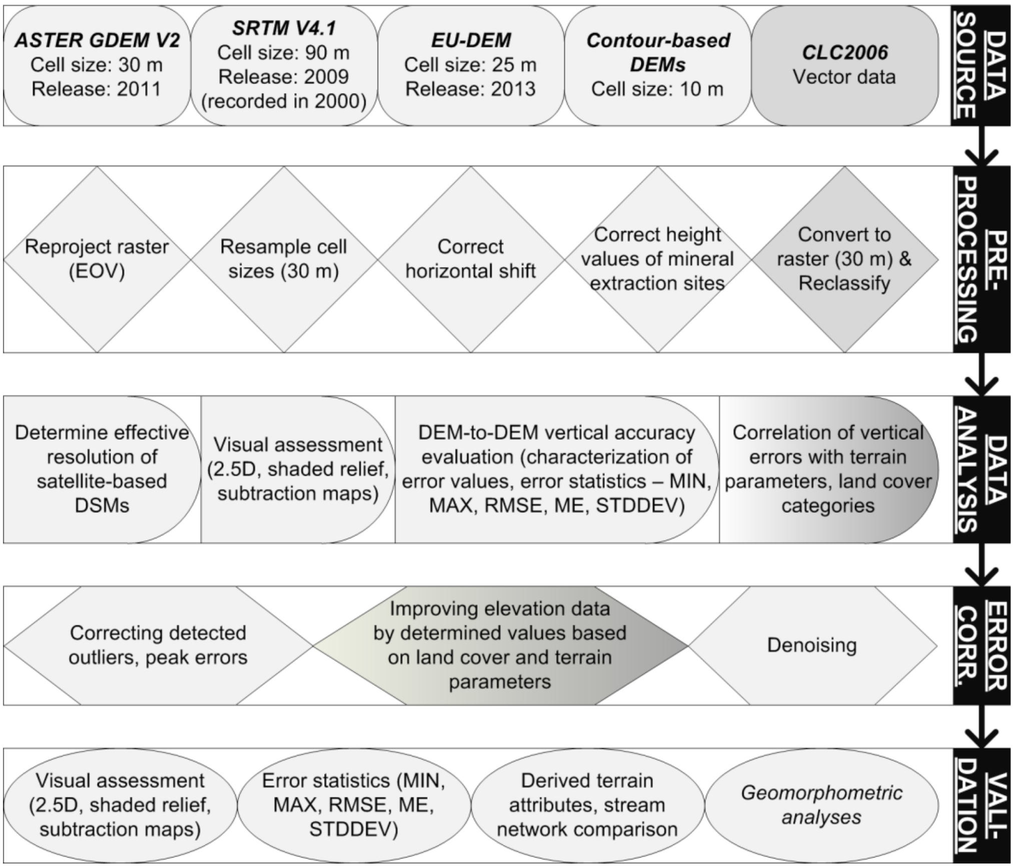

Fig. 2 The flow chart of the quality assessment

The spgrass6 package (Bivand, 2013) provided the R – GRASS interface, making it available to analyse the maps' statistics with the built-in and user-defined functions of R, and create graphs representing the results.

2.2 The EU-DEM V1 dataset

The EU-DEM is a middle-precision surface model with a horizontal resolution of about 25 m, published in October 2013. It was created by an automated data fusion of improved ASTER GDEM data with SRTM data, using a weighted averaging approach. Substantial steps of the data preparation was the removal of the GDEM's elevation values where the number of scenes was less than 5, cloud cover caused errors or extremely differing height values occurred and the filling of the voids with SRTM data. The concept of the model was to combine the advantages of both digital surface models with additional improvement by a new hydrography dataset and the NEXTMap data (Bashfield and Keim, 2011). The DSM is a realisation of the Copernicus programme, managed by the European Commission, DG Enterprise and Industry. The EU-DEM is available in 5° x 5° tiles from the website of the European Environment Agency[4] (EEA) or the European Commission[5]. As the data was provided without a formal validation, prior information about the horizontal and vertical accuracy has not been available yet (Frey and Paul, 2012).

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[4] http://www.eea.europa.eu/data-and-maps/data/eu-dem#tab-european-data

[5] http://epp.eurostat.ec.europa.eu/portal/page/portal/gisco_Geographical_information_maps/geodata/digital_elevation_model

2.3 The reference DEMs

The contour-based DEM of two sites over the study area was interpolated in SAGA GIS using the Triangulation method with 10 m cell size. The extent of these areas is approx. 130 km^2. The created elevation models were used to represent the ground-truth values for the error estimation methods after downsampling to 25 m in GRASS GIS. Manually digitising the contour lines and elevation points from the EOTR (Unified National Map System) topographic maps in scale of 1 : 10 000 provided the most accurate database at the lowest cost for the area. As stated by Engler and Mélykúti (2000) and Winkler (2007) the terrain information content of the maps meet the accuracy requirements of the T.1. Regulation, thus the accuracy of created DEMs are considered adequate to provide an acceptable quality assessment dataset for the fused EU-DEM model.

2.4 The CORINE Land Cover 2006 database

The seamless vector database of CLC2006 (Büttner et al., 2012) was downloaded from the EEA's site[6] and converted into a 25 m resolution raster dataset. Analysing the impact of the land cover on the elevation models was executed on 6 aggregated categories (Fig. 1), that was based on the height of the features (vegetation, buildings) or the potential error of the elevation values (mineral extraction, water bodies).

2.5 Modul r.geomorphon

For the geomorphological analysis of the study area a rather novel landform classification method, developed by Jasiewicz and Stepinski (2011, 2013) was chosen. This automated landform mapping approach departs significantly from the existing cell-based methods that classify the surface using different geomophometric variables. The method is based on the principle of pattern recognition – these patterns are the so called geomorphons (geomorphologic phonotypes) derived from the DEM. There are 498 geomorphons representing a comprehensive set of morphological terrain types, but the geomorphometric map is obtained by generalizing them and using only a small number of the most common landform elements. The greatest advantage of the method is that it self-adapts to local topography so basically it is not scale-dependent. Also the code is available in the public domain thus as an add-on tool it is easily installed into GRASS GIS (Stepinski and Jasiewicz, 2011).

3. Results

3.1 Quality assessment and error correction on the EU-DEM

The shaded relief maps (Fig. 3) and 2.5D visualization (NVIZ) are simple but effective tools to obtain preliminary information about the quality of the height datasets. The EU-DEM looks well-smoothed in NVIZ, which was expected according to the production method. However, the strong smoothing resulted in a loss of surface details, as it is shown on the 'blurry' shaded relief map. The subtraction maps provided the numerical data for the further error analysis, but they were useful to check the spatial distribution of positive and negative errors with the proper colour table (Fig. 4).

Validation reports and independent studies (ASTER GDEM Validation Team, 2009, 2011; Guth, 2010) about the ASTER GDEM and SRTM suggest that the models have a lower horizontal resolution than the 30 m spacing of postings, so it was assumed also for the fused model. The effective resolutions (Tab. 1) were determined using a method of Guth (2010). The reference DEMs were resampled to 10 different resolutions (10 to 100 m) and the mean slope values derived from every model were compared.

The error statistics[7] like the mean error (ME), the mean absolute error (MAE), the standard deviation of errors (SD) and the normal and "3σ rule" root mean square error (RMSE) (Aguilar et al., 2007) gave a general overview for the study area (Tab. 2). The error values were determined for the whole area and also separately for bare areas and forests. The ME shows a negative bias of 1.3 m over bare surfaces and the forested region is about~8 m higher than the reference DEMs.

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[6] http://www.eea.europa.eu/data-and-maps/data/clc-2006-vector-data-version-2#tab-metadata

[7] Height differences were determined by subtracting the reference DEMs from the EU-DEM, thus negative values represent areas where the reference models have higher elevation values.

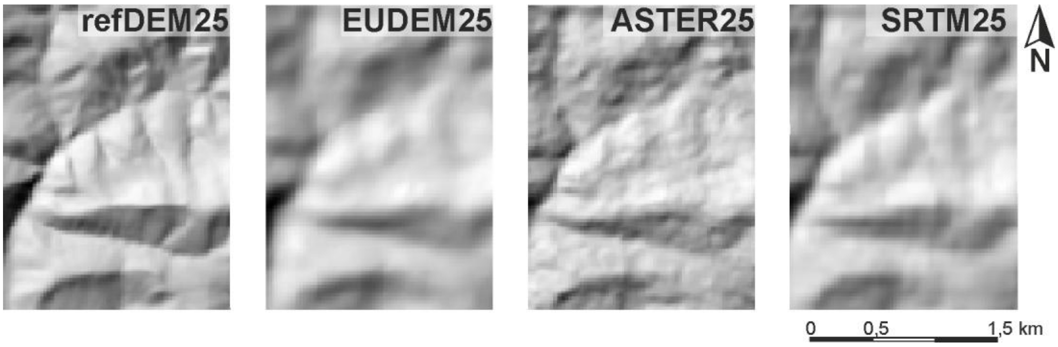

Fig. 3 Shaded relief maps of the models showing the Zengő and the upper parts of the Vasas-Belvárd stream's valley

Tab. 1 The effective resolution of the DSMs

	Spacing (m)	Resolution – former studies[8] (m)	Resolution – in this paper (m)
ASTER GDEM	30	~71	~56
SRTM	90	~97	~92
EU-DEM	25	n.a.	~68

Tab. 2 The change in error statistics

	Initial	Land cover correction	Denoising, smoothing
RMSE (m)	7.6	5.7	5.7
3σ RMSE (m)	6.4	5.0	5.0
ME (m)	2.0	~0.0	~0.0
MAE (m)	5.0	3.8	3.8
SD (m)	7.3	5.7	5.7

Over the forested areas with heterogeneous relief the correlation methods revealed the role of aspect for the height errors, similarly to earlier studies (Szabó, 2011; Szabó et al,. 2013). Accordingly the aspect categories were taken into account during the land cover based error corrections. The above mentioned denoising method was carried out with setting parameters in compliance with the study area (Stevenson et al., 2010; Sun et al., 2007).

After the correction of errors, the ME was around 0 m, but this can be a fallacious result. The MAE value remained around 2.3 m regarding the bare surface areas and 6.6 m over the forested parts. As a result of the error correction the percentage of cells with less than 1 m height deviation increased from 26% to 36%. The histogram of error values, made before and after the corrections, reflects clearly the decrease of height differences. This is evidenced by the subtraction map as well, on which the effects of forest removal and the "uplifting" of bare surfaces can be easily traced (Fig. 4). As a validation step the accuracy of slope and aspect as terrain derivatives was also checked. The slope values were reclassified according to the agricultural suitability (Pécsi, 1985). Generally, all of the DSMs derivatives look similar to the ones created from the reference DEMs. The valley networks – created on the basis of the reference DEMs and the EU-DEM with the same adjustments – show good correspondence: the numbers of cells rated as stream is similar and the ~75% of the stream cells of the EU-DEM based network are within a 100 m buffer zone of the reference DEMs stream lines.

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[8] The values presented were calculated based on the standard deviation of downsampled non-LiDAR DEMs and the DSMs over test areas in Japan and West Virginia (ASTER GDEM Validation Team, 2011).

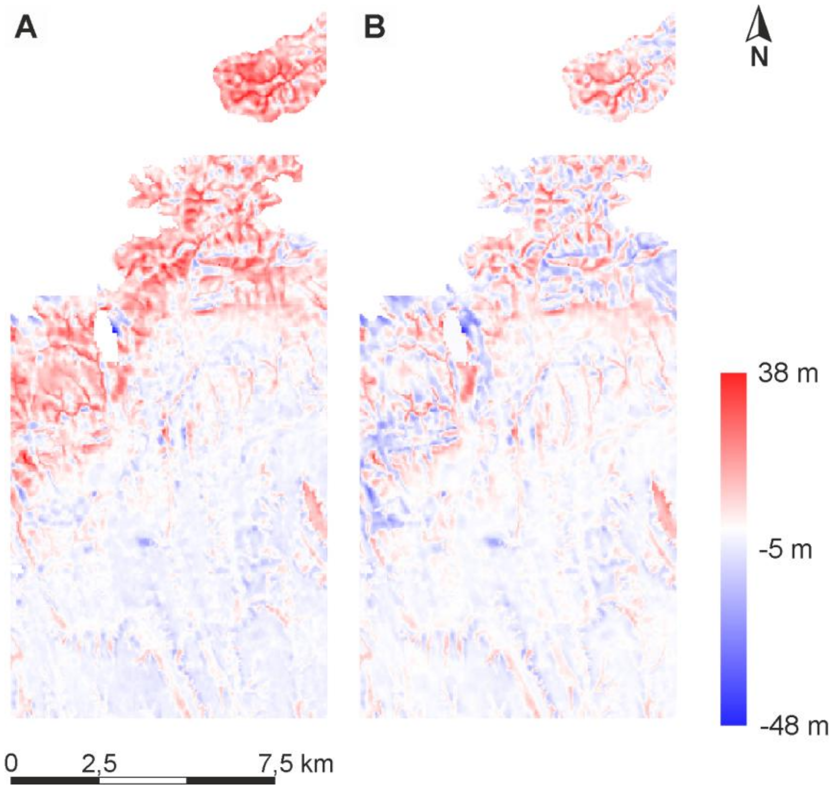

Fig. 4 The subtraction maps of the EUDEM before (A) and after (B) the corrections

3.2 Geomorphometric maps

The r.geomorphon is a user-friendly terrain analysing tool for the GRASS GIS software. The application calculates geomorphons and associated geometry using machine vision approach. The main input requirements are the elevation dataset, the lookup distance and the flatness threshold. The mentioned parameters are used to calculate the ternary pattern, which characterise the terrain type of the central cell based on the examined neighbourhood. The main advantage of the chosen method is that it uses the line-of-sight approach to automatically fit the cell-matrix to the terrain in order to achieve flexibility in the size of the mapped geomorphons (Jasiewicz and Stepinski, 2013; Stepinski and Jasiewicz, 2011).

The two maps below (Fig. 5) show the impact of smaller and higher lookup distance for the delineated landforms. In the case of the flat regions the maps are almost similar. As the neighbourhood that the method could use for the examination of terrain patterns is growing the valleys and ridges are more robustly separated from the slopes.

Analysing the geomorphic content of the maps the following observations can be made.

- The extensive flat regions in the southern part of the geomorphometric maps can be interpreted as the residual piedmont surface of the Mecsek Mountains (Pécsi, 1963).
- The dense channel network of the northern part of the study area is also well-defined on the maps.
- The radial horst ranges around the highest peaks of the mountain are recognizable (Ádám et al., 1990).

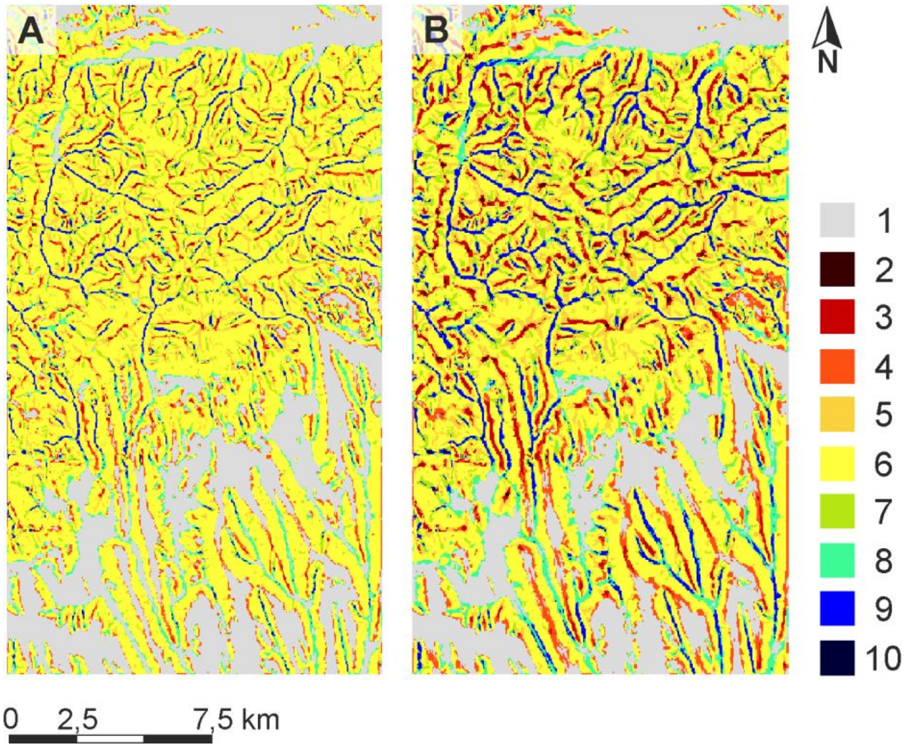

Fig. 5 Geomorphic maps of the study area created by the r.geomorphon using 150 m (A) and 350 m (B) lookup distance and 2.5° flatness threshold – 1 = flat; 2 = summit; 3 = ridge; 4 = shoulder; 5 = spur; 6 = slope; 7 = hollow; 8 = footslope; 9 = valley; 10 = depression

Conclusions

The EU-DEM satellite-based DSM had different elevation errors over the study area, so analysing the error statistics and distribution is recommended before applying. The horizontal misfit of the model was confirmed and corrected by comparing the location of peaks. The calculated effective resolution showed that the models horizontal spacing is over-estimated, resulting greater storage capacity requirements.

The height differences caused by the land cover were treated by lowering elevation data or uplifting the surface according to mean errors of the categories. Based on the results, it seems to be a time-saving solution to alter a larger study area with values determined for smaller, but representative reference sites. The used denoising method also improved the model, and it is suggested even for just visualizing goals too.

The validation process showed that there are still some errors that need to be corrected, and the parameterization of the denoising method could be more precise, but in all the EU-DEM is suitable for geomorphologic studies in similar study areas.

The r.geomorphon add-on in GRASS GIS provides a computationally efficient tool for non-scale dependent landform classifications of heterogeneous terrain like the Eastern Mecsek Mountains. The method produced an easily adaptable generalized geomorphological map. Comparing the literature and the findings of the landform mapping the study concluded that the EU-DEM is an acceptable height database for DEM-based geomorphological analyses.

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Resumé

Hodnotenie použiteľnosti digitálneho výškového modelu EU-DEM pre klasifikáciu geomorfologických foriem prostredníctvom geomorfónov: prípadová štúdia východnej časti pohoria Mecsek

Analýzy voľne dostupných digitálnych modelov povrchu EU-DEM pre východnú časť pohoria Mecsek potvrdil horizontálne a vertikálne chyby vyplývajúce z charakteristík základných modelov použitých pre tvorbu EU-DEM (ASTER GDEM, SRTM), ďalej z vplyvu pôdneho krytu a taktiež z metódy fúzie základných modelov. Preto hodnotenie kvality a korekcia chýb predstavovali veľkú časť výskumu. Horizontálne chyby v celej študovanej oblasti možno opraviť použitím vrcholkov hôr so známou pozíciu (buď kontrolou súradníc alebo ich odlíšením na referenčných výškových modeloch). Vypočítané efektívne rozlíšenie ~68 m je viac než dvojnásobkom vzdialenosti, ktoré možno pripísať efektu zhladzovania. Vizuálne metódy vyhodnocovania (2.5D vizualizácia, tieňovaný reliéf, rozdielové mapy) sa ukázali byť jednoduché, ale účinné nástroje na získanie predbežnej informácie o kvalite dátového súboru, a tiež umožňovali skontrolovať výsledky úprav. Odčítanie výškových modelov navzájom bolo použité pre výpočet špecifických chybových štatistík, ktoré boli stanovené pre celú oblasť, a tiež zvlášť pre otvorené a zalesnené plochy. Tieto chybné hodnoty číselne potvrdili prítomnosť nesprávnych údajov o nadmorskej výške v modely EU-DEM. Oprava bola vykonaná v niekoľkých krokoch: najprv boli odstránené plochy s veľkými chybami a hlavná časť úpravy sa vykonala pomocou mapy krajinnej pokrývky a expozície reliéfu, napokon bolo odstránený dátový šum.

V druhej časti štúdie sme sa zaoberali aplikáciou, tzv. metódu geomorfónov. Táto metóda je novým výpočtovo efektívnym nástroj pre mierkovo nezávislú klasifikáciu foriem reliéfu. Je k dispozícii ako modul r.geomorphon pre GRASS GIS softvér s otvoreným zdrojovým kódom. Podľa výsledkov EU-DEM, opravený o chyby, poskytuje ako vstupný súbor prijateľné výstupy geomorfometrických parametrov pre výškovo heterogénne povrchy, ako sú nízke pohoria. Zovšeobecnené geomorfologické mapy zobrazujú formy reliéfu, ktoré sú dobre identifikovateľné pre zistené efektívne rozlíšenie EU-DEM. Metóda bola schopná odlíšiť typické formy charakterizujúce topografiu východnej časti pohoria Mecsek, rovnako ako zvyšky piedmontu v južnom predpolí, hustú údolnicovú sieť a radiálne sa rozbiehajúce hrásťové chrbty v severnej časti.

Obr. 1 Lokalizácia záujmového územia (taktiež sú vyznačené hranice mikroregiónov a oblasti Natura 2000 SCI), zobrazenie EU-DEM (A) naložené referenčné výškové modely DEM a agregované kategórie krajinnej pokrývky CLC2006 (B). 1 = urbanizované plochy a súvisiace oblasti; 2 = orná pôda a iné nezakryté plochy; 3 = lesy; 4 = plochy pokryté stredne vysokou vegetáciou; 5 = ťažobné areály; 6 = vodné plochy

Obr. 2 Schéma hodnotenia kvality

Obr. 3 Tieňovaný reliéf digitálnych modelov terénu ukazujúcich Zengő a hornú časť údolia rieky Vasas-Belvárd

Obr. 4 Rozdielové mapy oblasti EU-DEM pred (A) a po (B) opravách

Obr. 5 Geomorfologické mapy študovanej oblasti vytvorené modulom r.geomorphon použitím nastavenia polomeru vyhľadávania 150 m (A) a 350 m (B), s prahom plochosti 2,5°. 1 = plošina; 2 = vrchol; 3 = hrebeň; 4 = plece svahu; 5 = svahový odpočinok; 6 = svah; 7 = svahová vyhĺbenina; 8 = úpätie; 9 = dolina; 10 = bezodtoková vyhĺbenina (depresia).

Tab. 1 Efektívne priestorové rozlíšenie digitálnych modelov povrchu (DSM)
Tab. 2 Zmeny v štatistikách chýb

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