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DEM from topographic maps
- as good as DEM from LiDAR?

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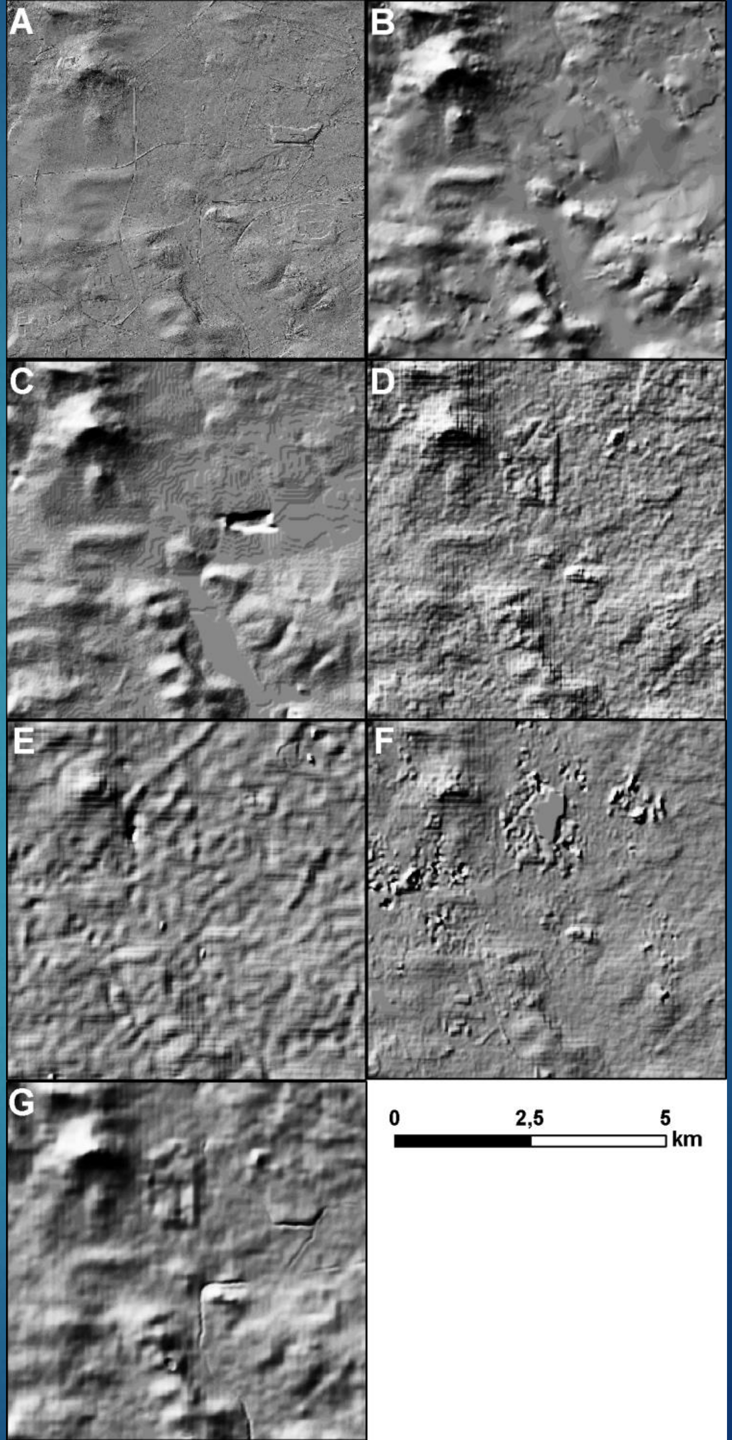
Introduction (1)

Digital elevation models are commonly used in earth sciences and play a central role in environmental modelling across a range of spatial scales. There are many freely-available global DEMS (ASTER GDEM, AW3D30, DTED-2, EU-DEM, SRTM,…), but their quality is not always sufficient for conducted studies.

If we talk about the local scale, DEM resolution of 25-30 m is usually too low. Obviously, low spatial resolution of the DEMs affects their low accuracy (horizontal and vertical).

For this reason, higher resolution models must be used. As we know, nowadays the most accurate height data for creating high-resolution models are ALS/LiDAR data.

Unfortunately, they are not always available for all interesting areas, especially if we are interested in comparative analyzes with historical data.



Hillshaded maps:

A - LiDAR-DEM
B - Topo-DEM
C - DTED-2
D - SRTM
E - ASTER GDEM
F - AW3D30
G - EU-DEM

Introduction (2)

Topographic maps come to our rescue, because they are an extremely valuable source of information about the heights and nature of the relief of a given area. **Contour lines** in combination with **height points** and **water bodies and flows** are **great material for creating digital elevation models**.

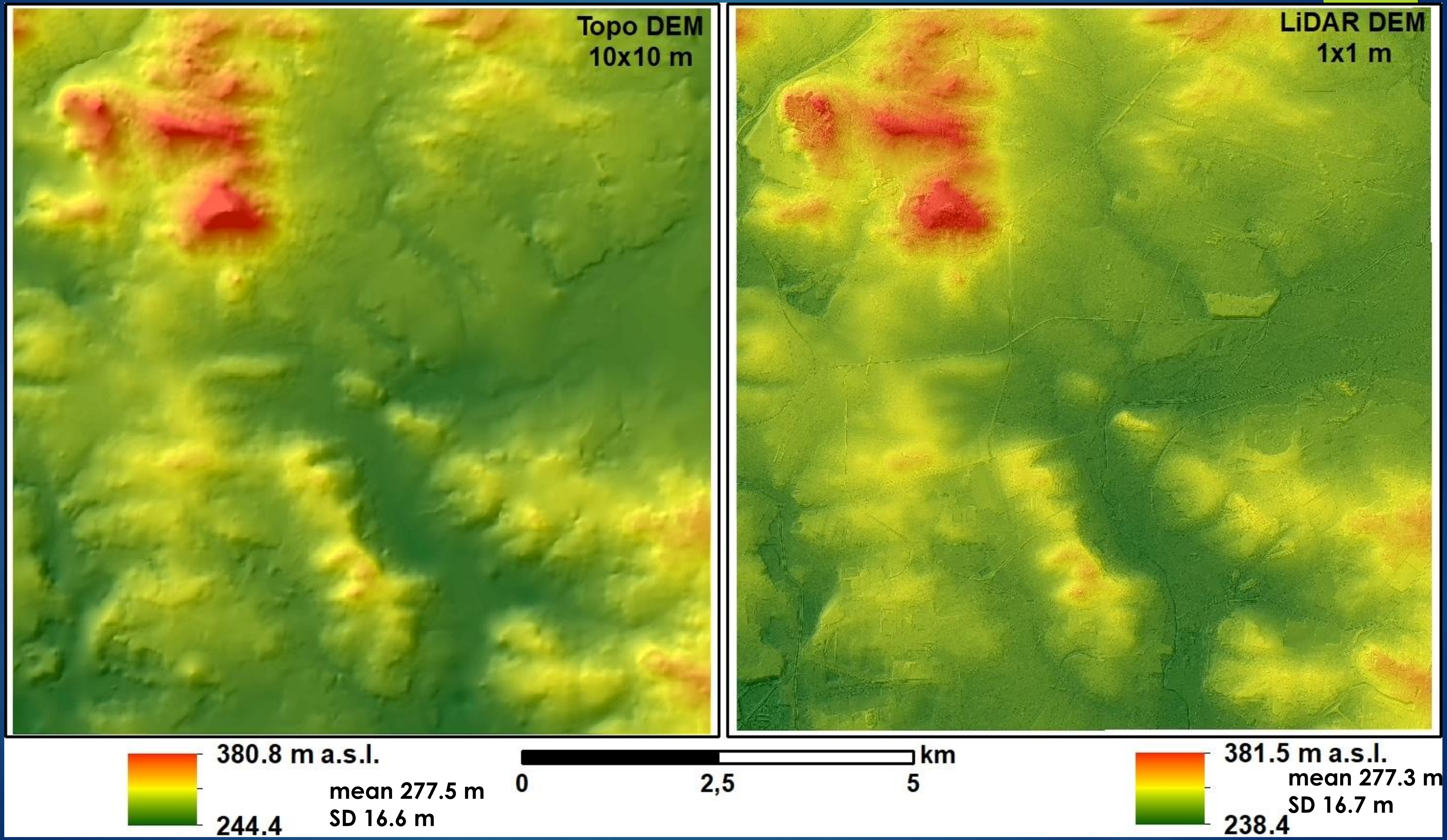
The main goal of this study was to carry out investigations into the quality assessment of DEM derived from topographic maps (Topo-DEM) for geomorphometric purposes. To achieve this goal it was decided to compare the accuracy of Topo-DEM with reference to DEM derived from laser scanning (LiDAR-DEM).

I tried to answer the questions: **What is the vertical accuracy of Topo-DEM versus LiDAR-DEM?** and **Can a Topo-DEM produce similar results for geomorphometric analyses to LiDAR-DEM?**

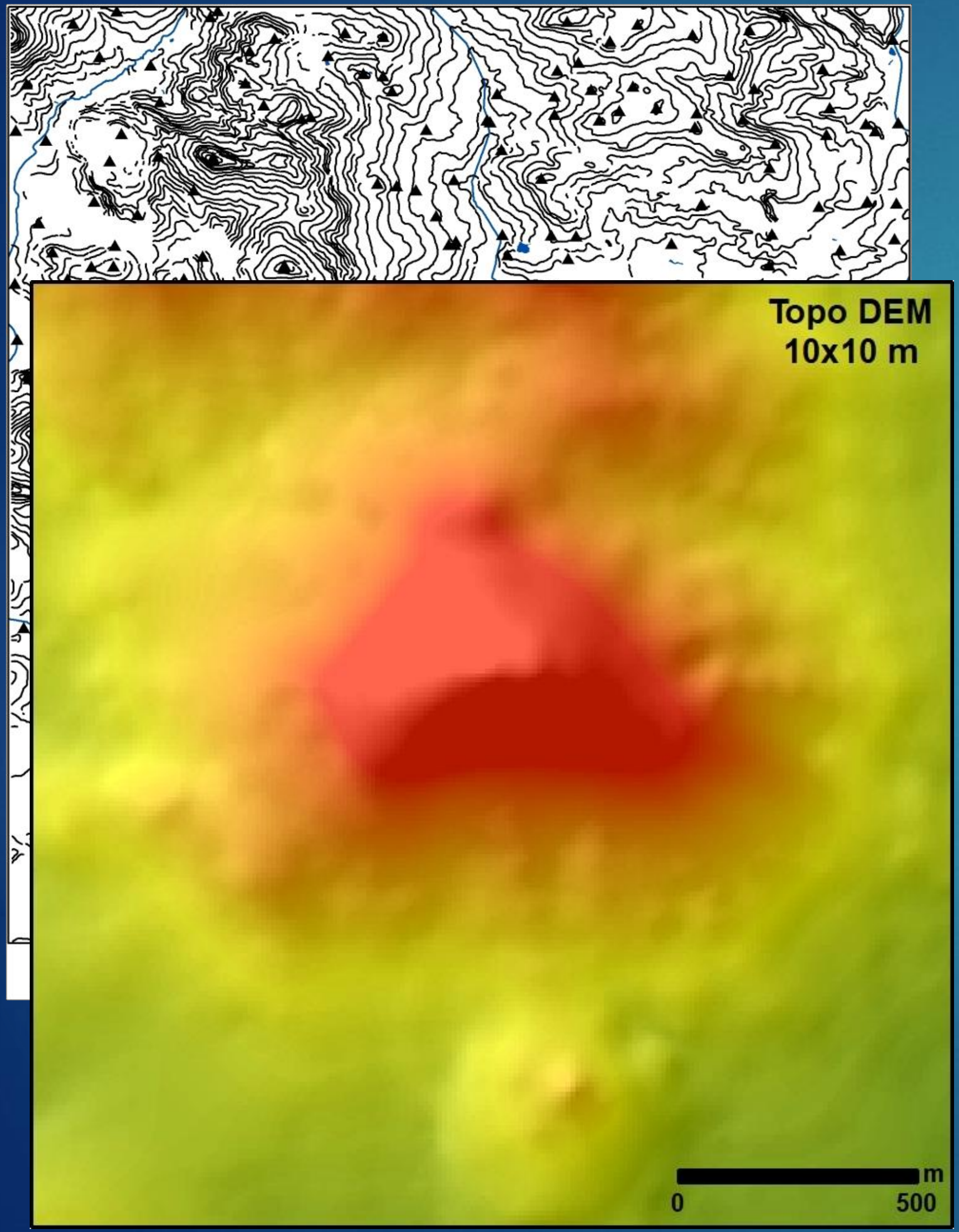
To answer these questions:

1) comparison of elevation differences between a Topo-DEM and a LiDAR-DEM were done,
2) calculations of basic geomorphometric parameters were done,
3) landform classification using Topographic Position Index were conducted.

Source data (1)



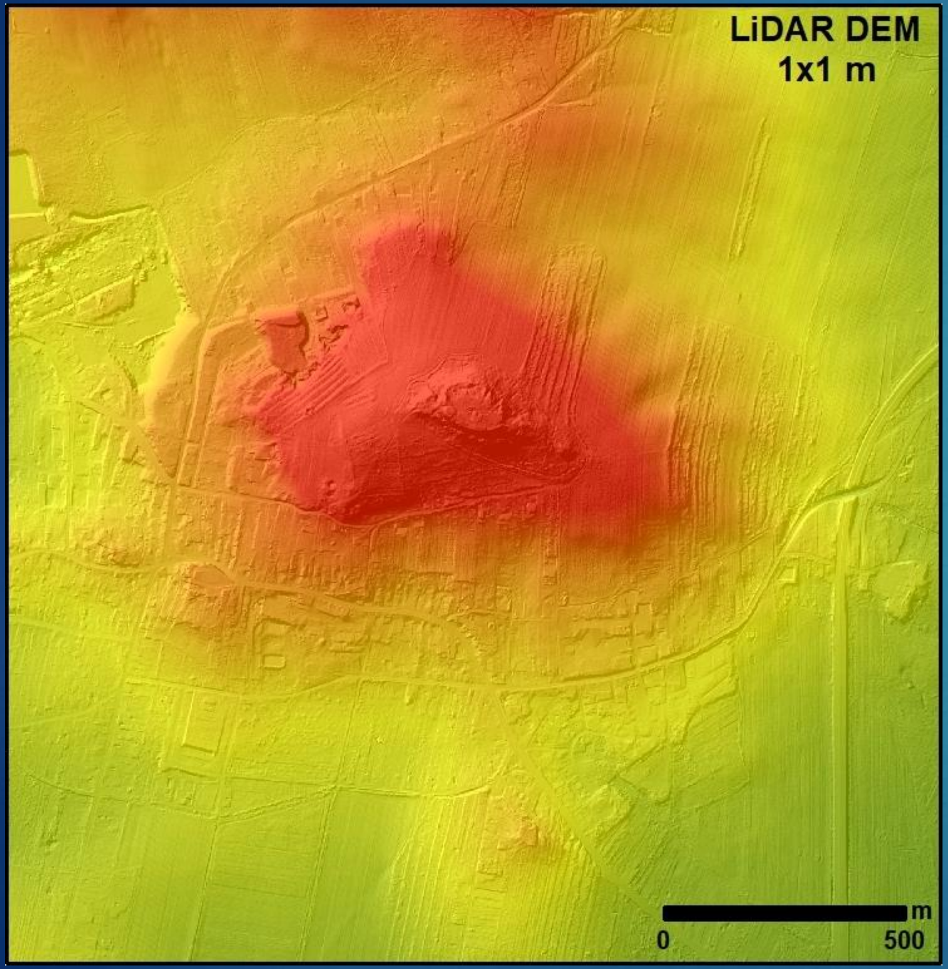
Source data (2)



Base for the Topo-DEM were 4 sheets of the topographic maps in 1:10,000 (747 km of contour lines and all 362 height points were digitized. Moreover all watercourses and water reservoirs with an area 500 m^2 were used as breaklines. together with contours and height points to support the interpolation proces. Following the cartographical rule, that one should always compile a map from source materials of the same or larger scales - since the scale of the source maps was 10,000 (if the smallest polygonal object on the map is 1×1mm - in reality it is 10×10 m) it was decided to build a DEM with the resolution of 10×10 m.

Topo-DEM was made in PUWG-1992 (EPSG: 2180) coordinate system, and the heights of points relate to the Normal Height System Kronsztadt 86. Digitalization and all DEM analyses and calculations were performed in the ArcGIS software. One have used the Topo-to- Raster tool from ArcGIS Toolbox which applies an interpolation method specifically designed to create a surface that more closely represents a natural drainage surface and better preserves both ridgelines and stream networks from input contour data. This technique creates hydrologically correct DEMs and is based on the ANUDEM algorithm developed by M.F.Hutchinson.

Source data (3)



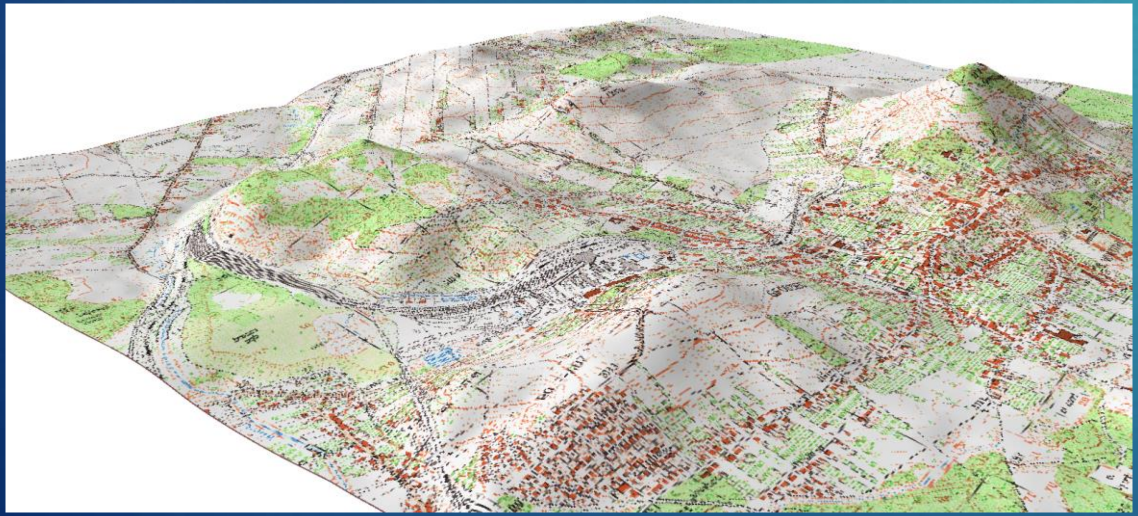
LiDAR-DEM is a digital elevation model derived by Airbone Laser Scanning (ALS) with 1x1 m horizontal resolution and vertical accuracy of 0.2 m. All elevation data are using the PUWG 1992 (EPSG: 2180) coordinate system and the heights of points relate to the Normal Height System Kronsztadt 86. This DEM is in ESRI ASCII Grid (asc) format. The source data used to create this DEM were LAS files. Every LAS dataset file contains an average of 7.5 points/m^2 for the entire area. This format consists of header information containing a set of parameters which can be used to geocode the data. Although the header includes the coordinates of the lower left corner of the area covered by the grid, the elevation data are given as strings of elevations, row by row, starting from the upper left point on the grid.

Methods (1)

The performed analyses related to Topo-DEM quality assessment can be divided into three basic stages:

1) preliminary visual assessment based on topographic maps

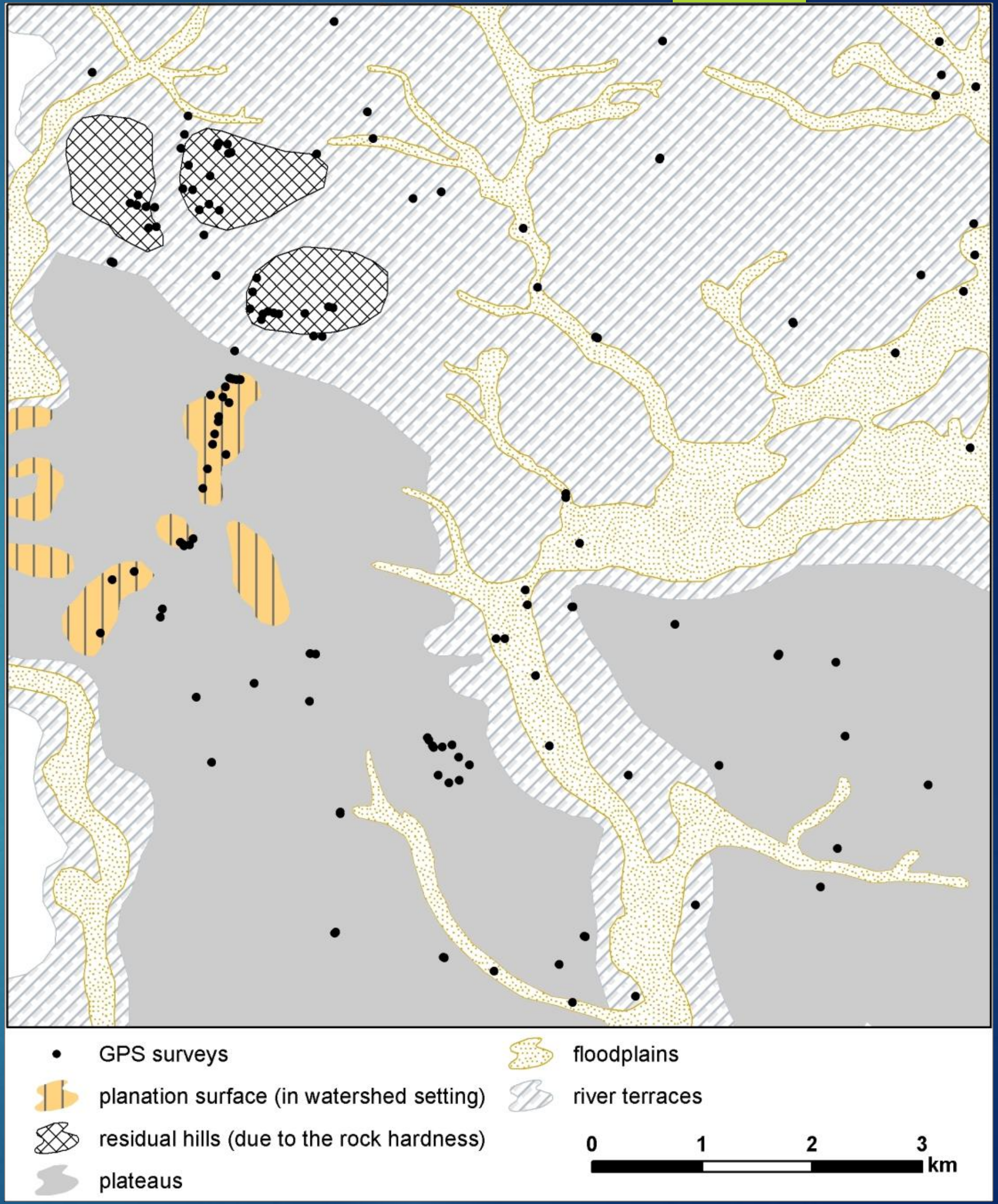
The first stage consisted in the observation of the model in a 3D view with a topographic map draped on a DEM. Owing to this, the explicit spatial position of the most important elements of the topography (river valleys, the course of ridges, peaks, etc.) was verified. Then, the course of contours generated from the model was compared with original contours from topographic maps. In the last step, 100 checkpoints were randomly generated for which elevations read from the topographic map and from the Topo-DEM were compared.



Methods (2)

2) the juxtaposition of altitude accuracy with field measurements. Vertical accuracy is one of the most important features of DEMs, sometimes accuracy assessment of a DEM is carried out by comparing DEM points and reference checkpoints.

Moreover the American Society of Photogrammetry and Remote Sensing (ASPRS) recommends a minimum of 20 checkpoints in each of the major landform categories. According to the above assumptions, reference data were derived by ground surveying with using high precision GPS RTK Leica Viva CS10. In total, 149 points for the entire area were measured (average accuracy of all the GPS RTK surveyswas 1cm horizontal and 1.3 cm vertical).



Methods (3)

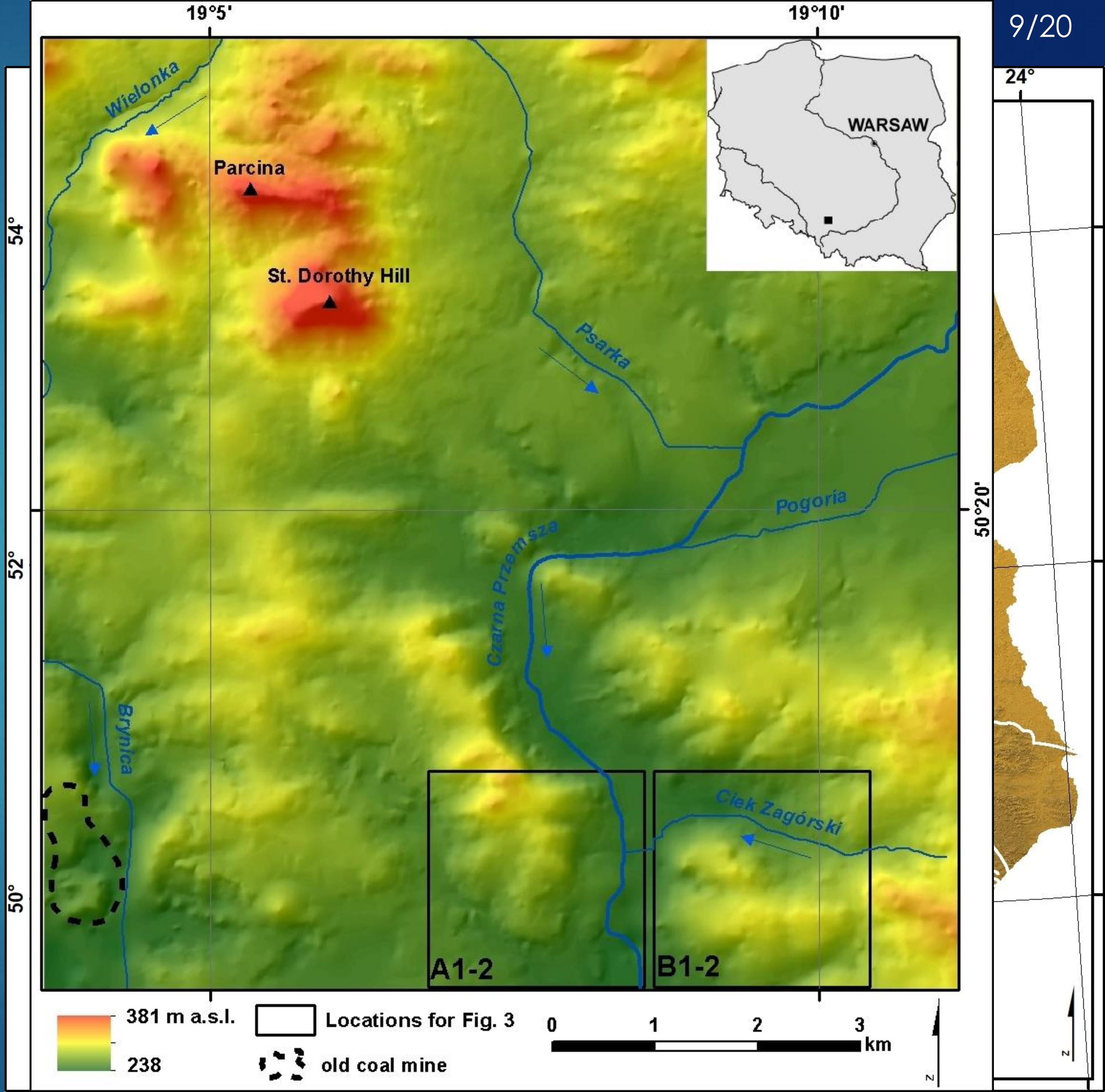
3) comparison of the elevation and geomorphological accuracy with LiDAR-DEM. Rieger (1996) proposed comparing a target DEM with a "reference" DEM (for us it is LiDAR-DEM). Apart from absolute accuracy of DEMs (vertical and horizontal), in geomorphometry and geomorphology we are often more interested in land-surface parameters; how accurately DEM reflects the actual shapes and flow/deposition processes of the land surface? It is the 'relative' or 'geomorphological' accuracy of DEMs, which defines a general situation of the topography of a given area, emphasizing the most important relief features and faithfully reproducing the nuances and details of the relief, depending on the DEM spatial resolution.

Apart from the parameters derived from DEM (altitude, aspect, slope, curvature) and statistical measures (local relief, standard deviation, etc.) the classification of landforms was made. The Topographic Position Index was used to distinguish landforms. TPI it is a classification system based on the difference between a cell elevation value and the average elevation of the neighborhood around that cell. Positive values mean the cell is higher than its surroundings (summit or near the top of a hill or a ridge), while negative values mean it is lower (at or near the bottom of a valley). TPI values near zero could mean either a flat area or a mid-slope area.

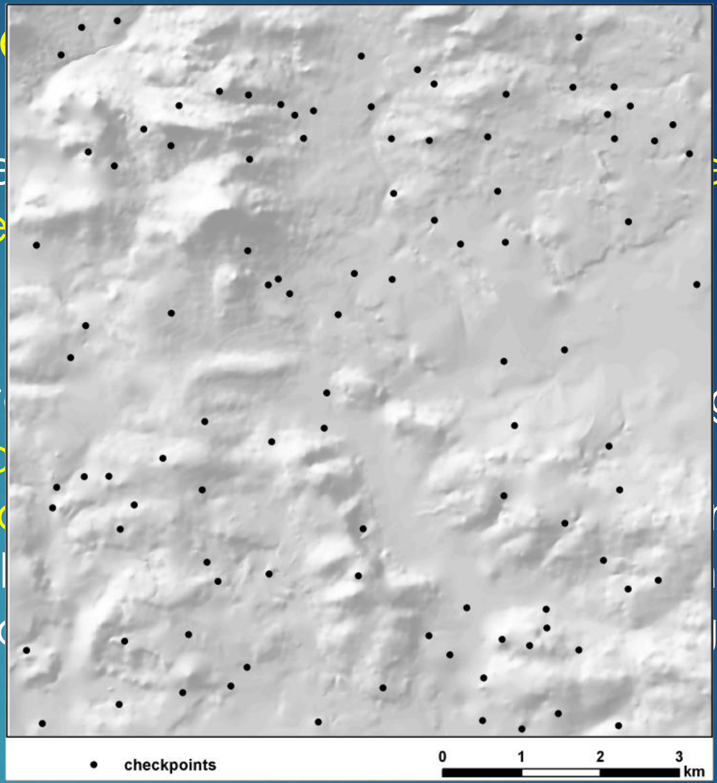
Study area

The study area is located in southern Poland, in the Silesian-Cracow Upland, which belongs to the strip of Polish Uplands. The midpoint of the research area is situated at 50.3° N latitude and at 19.1° E longitude. This area covers over 82 km^2.

Local relief is 136 m and the average altitude is 277 m a.s.l. The highest elevations, are St. Dorothy Hill (381 m a.s.l.) and Parcina Hill (355 m a.s.l.) located in the NW part of the area and the lowest place - an old coal mine area (238 m a.s.l.) in the SW part. The main drainage river is Przemsza with its tributaries and fragment of Brynica with its tributary Wielonka. This area is diverse enough to show different types of landforms but, at the same time, it has well-recognized topography, which constitutes the reason for its selection.

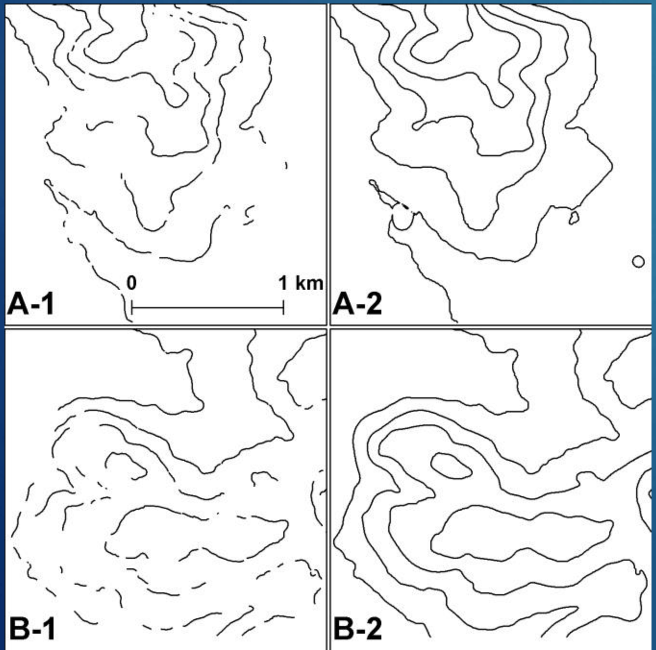


Results - Topo-DEM versus source topogr



1) visual evaluation of a Topo-DEM model in 3D showe … ects the general character of the morphology of the study are … of the relief related to human activity were visible.

2) all the 10 m contours from the model were generat … ginal contours from the topographic maps. The vast majority of the c … odel exactly matched the original course of the contours from topo … ng the total length of both sets of the contours, it turned out that t … e DEM are 25% more. This is due to incomplete selection of the c … raphic maps, especially in urban areas (with compact buildings).



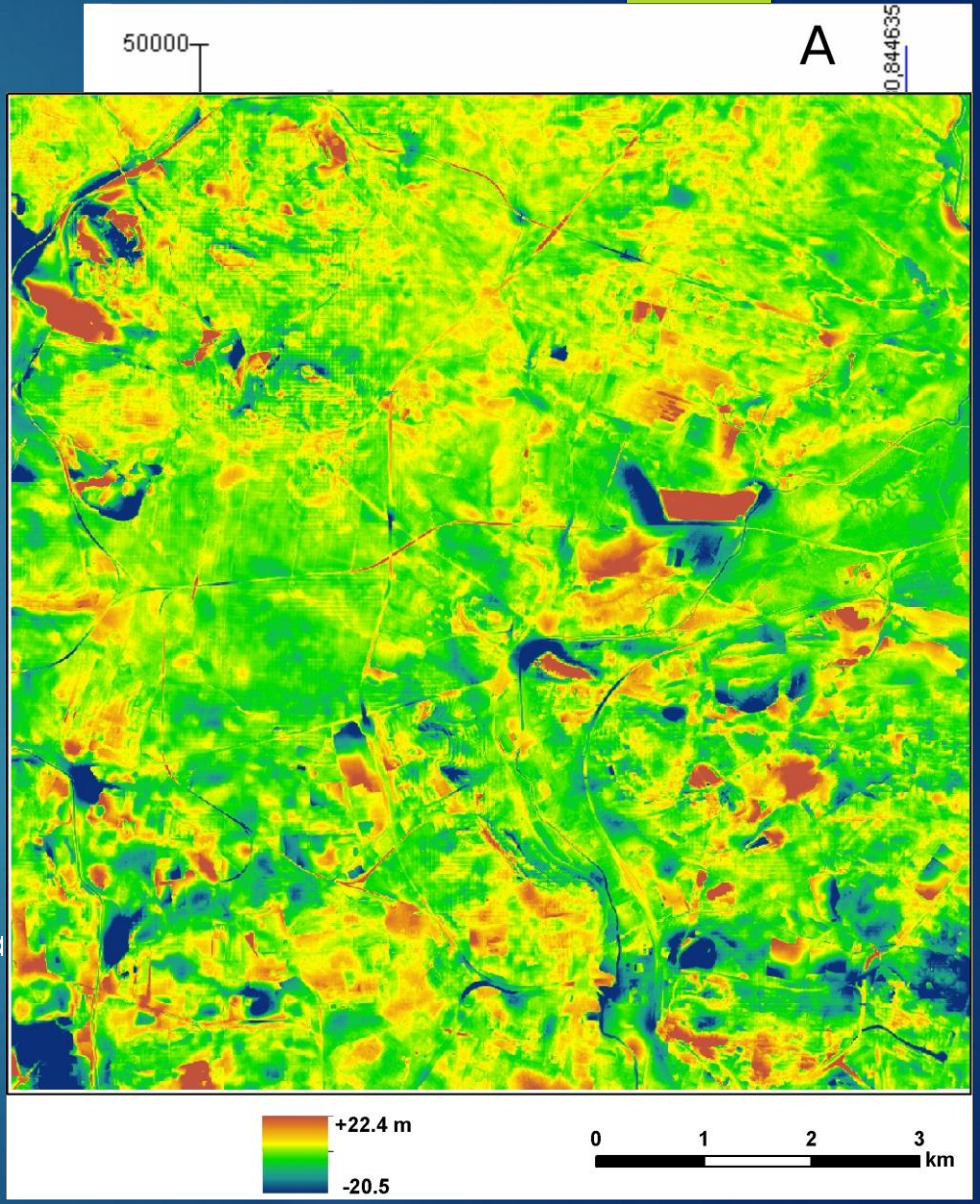
3) 100 checkpoints were randomly generated, for which elevations from the topographic maps were read and compared with the elevations obtained from the Topo- DEM model. The differences in the compared elevations ranged from −1.68m to +2.06 m. The values of the MAE and RMSE were < 0.2 m, and SD was 0.4 m, which is a very good outcome, because some researchers stated that for data obtained from a topographic map at the scale of 1:10,000, the average altitude error is in the range from 0.8 to 2.0 m.

Results - Topo-DEM versus LiDAR-DEM - **elevation differences** (1)

1) The histograms with elevation distribution of both DEMs are similar and show typical right-skewed (positive) distribution. This situation indicates the prevailing number of altitude values below average elevation values.

2) Results of elevation differences between Topo-DEM and LiDAR–DEM were calculated and they are as follows: the value −20.5 m represents the negative maximum error and the values + 22.4 m refer to positive maximum error. However, these extremely high values did not affect small MAE (1.16 m), RMSE (1.69 m) and SD (1.83 m) because errors bigger than ±10 m are only 0.34% of all compared values.

The largest elevation differences occurred in places heavily transformed by man: a sewage treatment plant, a former coal mine or a rubbish dump. These are the areas with the smallest number of height information (the course of the contours was uncertain and often incomplete and there were no height points).



Results - Topo-DEM versus LiDAR-DEM - **elevation differences** (2)

3) But some researchers noted that results substantiate the finding that the accuracy provided in form of RMSE alone is not sufficient to assess the quality of DEM. So, I decided to calculate the result conformity of elevations between two DEMs, which I proposed earlier (Szypuła, 2016). This method consists in comparing both DEMs cell-by-cell and calculating the differences between them. Herein, result conformity values express how many percent of the Topo-DEM grid cells are in accordance with the same grid cells of LiDAR-DEM. Conformity was calculated for different elevation ranges: ± 0.1 m, 0.25 m, 0.5 m, 1.0 m and 2.0 m (Table). It is interesting that more than 63% of the study area has result conformity value for the height difference of ± 1m and for more than 86% of the area it is ± 2 m. Obviously, the greater the elevation range, the higher result conformity. It generally shows how accurate Topo-DEM is.

Range of elevational differences [m]	Percentage [%]
−0.10 - 0.10	7.9
−0.25 - 0.25	19.6
−0.50 - 0.50	37.4
−1.00 - 1.00	63.4
−2.00 - 2.00	86.1

Results - Topo-DEM versus LiDAR-DEM - **basic geomorphometric parameters** (1)

Table presents used geomorphometric parameters and their statistics:

1) Altitude – values are very similar; only the minimum values differ in 5 meters between the DEMs, this mainly concerns the SW fragment of the area where anthropogenic landforms are located

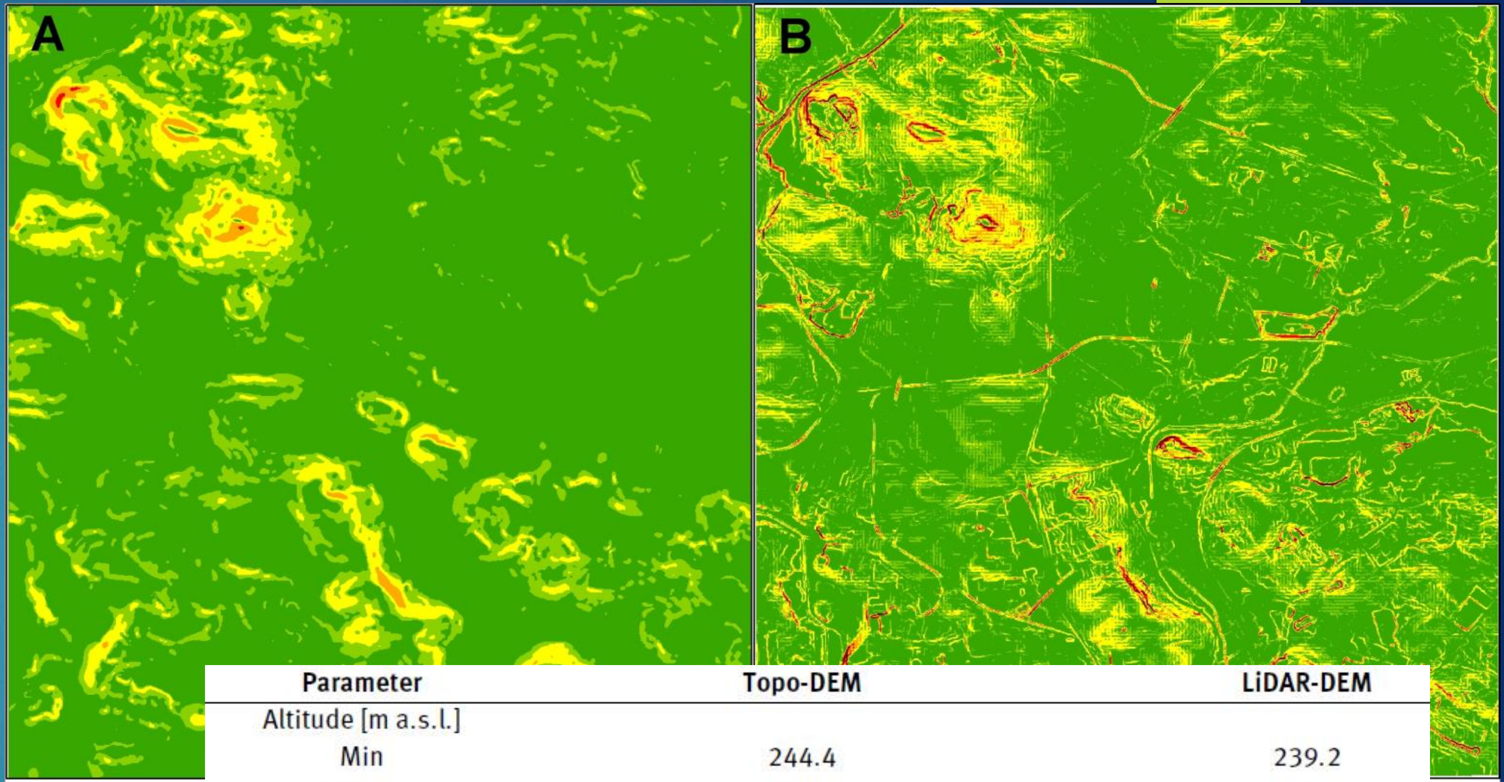
2) Local relief (altitude range between the highest and the lowest points). Calculations were made in filter windows (3×3, 10×10 and 25×25 cells) to check how the values are distributed. Results in table show that the biggest differences between the models occur for the 3×3 cells neighborhood. This situation confirms much greater detail of LiDAR-DEM compared to Topo-DEM. The larger the filtering window (neighborhood) is, the more convergent and similar the results are.

Parameter		Topo-DEM			LiDAR-DEM	
Altitude [m a.s.l.]						
Min		244.4			239.2	
Max		380.8			381.0	
Mean		277.5			277.3	
SD		16.6			16.7	
Local relief [m]	3×3	10×10	25×25	3×3	10×10	25×25
Min	0.0	0.0	0.1	0.0	0.1	0.9
Max	8.9	32.4	63.4	19.1	38.6	64.8
Mean	0.9	3.9	9.8	1.3	5.0	11.3
SD	0.8	3.3	7.2	1.3	3.6	7.2
Slope [°]						
Min		0.0			0.0	
Max		18.5			41.1	
Mean		2.00			2.67	
SD		1.78			2.87	
Curvature [1/100 of m]						
Min		−5.48			−24.01	
Max		3.87			25.40	
Mean		−0.02			−0.10	
SD		0.10			1.28	
Aspect [°]			%			
N (337.5-360.0, 0.0-22.5)		11.0			11.8	
NE (22.5-67.5)		10.5			11.2	
E (67.5-112.5)		12.0			12.3	
SE (112.5-157.5)		13.5			12.9	
S (157.5-202.5)		17.9			17.6	
SW (202.5-247.5)		16.0			14.3	
W (247.5-292.5)		10.2			11.0	
NW (292.5-337.5)		8.8			9.1	

Results - Topo-DEM versus LiDAR-DEM - **basic geomorphometric parameters** (2)

3) Slope (the maximum rate of change in value from that cell to its neighbors) The spatial image of the calculated slopes is very similar to the local relief in the 3×3 cells neighborhood. Certainly, LiDAR-DEM shows a lot of small forms (lines of embankments and road incisions) that cannot be seen on Topo-DEM. However, the main features of the relief are very clear: St. Dorothy Hill in the NW, the wide valley of the Czarna Przemsza river in the central part and rows of ridges on its both sides in the south of the area.

Higher maximum slope values occur in LiDAR-DEM but the mean and SD values are more similar.



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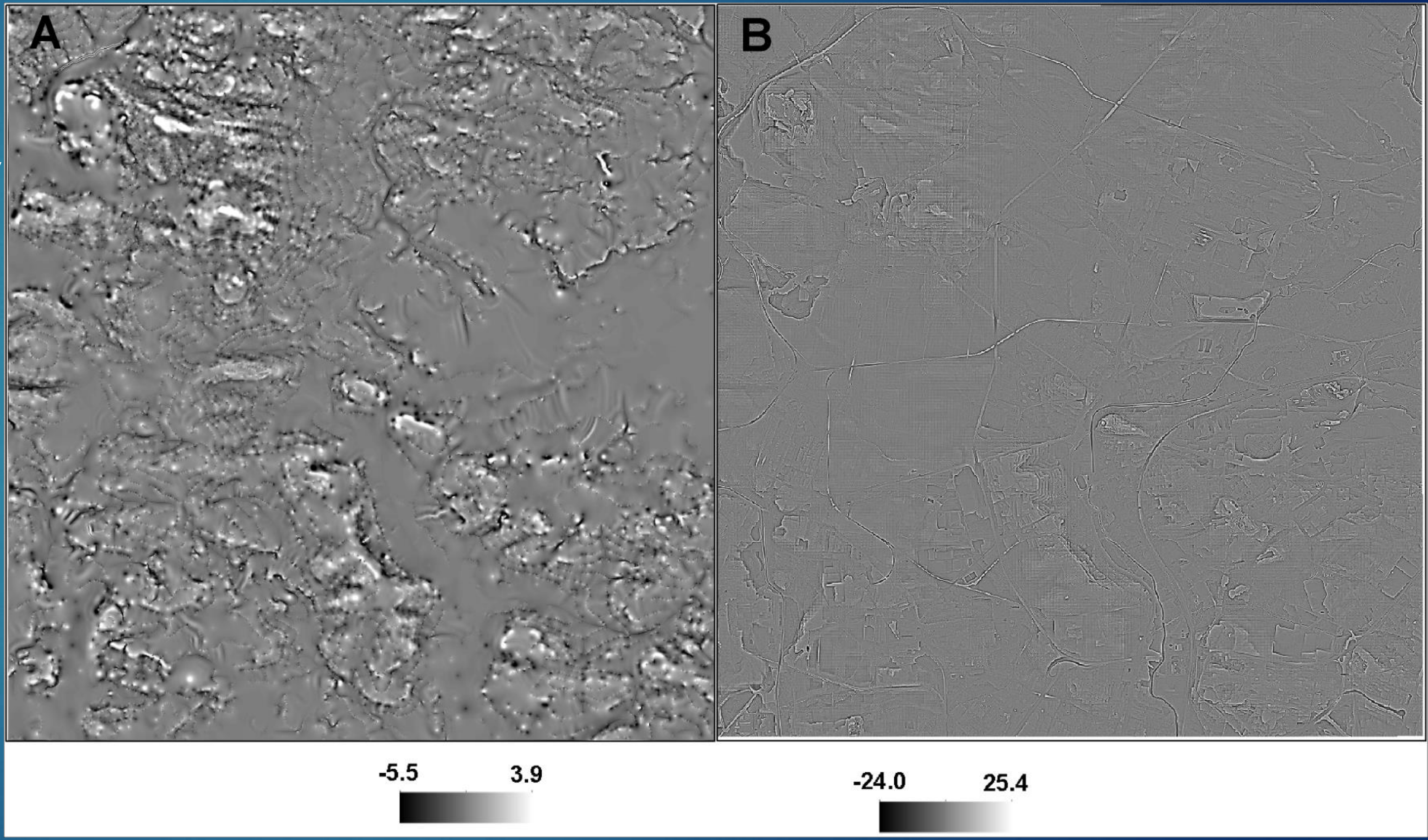
Altitude [m a.s.l.]					
Min		244.4			239.2
Max		380.8			381.0
Mean		277.5			277.3
SD		16.6			16.7
Local relief [m]	3×3	10×10	25×25	3×3	10×10
Min	0.0	0.0	0.1	0.0	0.1
Max	8.9	32.4	63.4	19.1	38.6
Mean	0.9	3.9	9.8	1.3	5.0
SD	0.8	3.3	7.2	1.3	3.6
Slope [°]					
Min		0.0			0.0
Max		18.5			41.1
Mean		2.00			2.67
SD		1.78			2.87

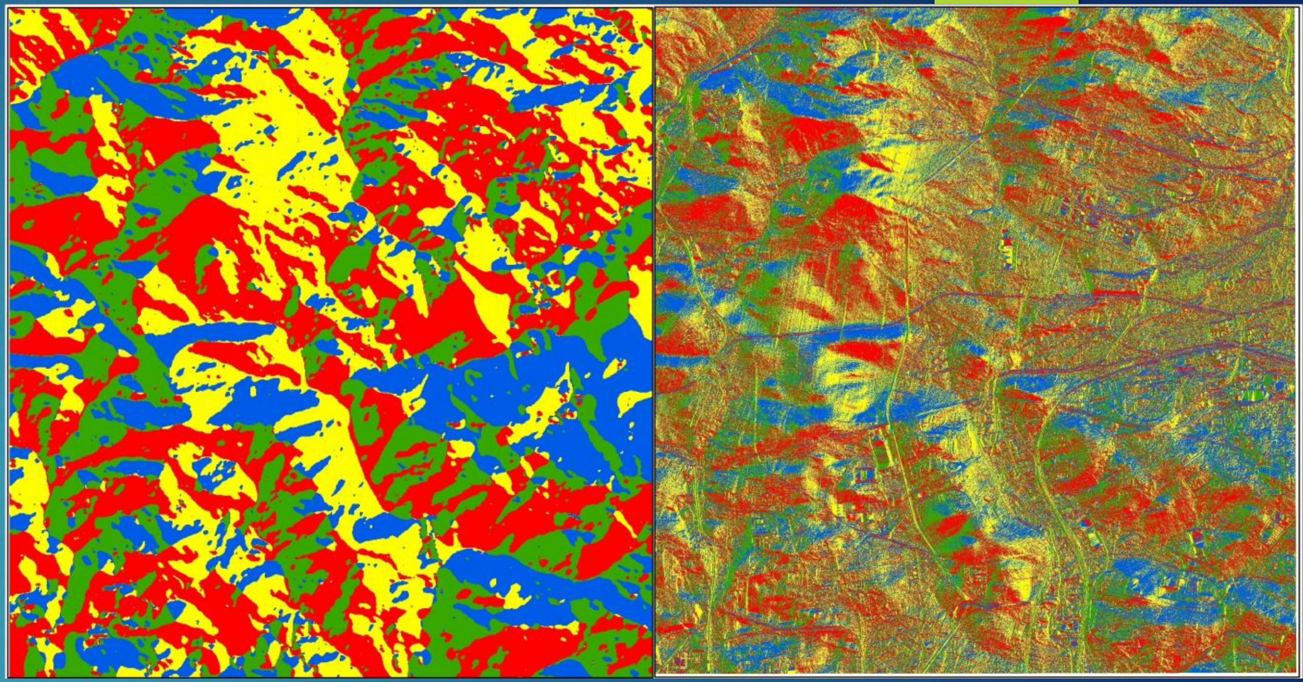
Results - Topo-DEM versus LiDAR-DEM - **basic geomorphometric parameters** (3)

4) Curvature (one used standard curvature, which combines both the profile and plan curvatures, the units are 1/100 of meters). Usually, expected values for a hilly area (moderate relief) can vary from −0.5 to +0.5, while for steep and mountainous relief the values can be much higher. In this case, a picture of spatial distribution is much more interesting than the values themselves. The curvature map on the basis of Topo-DEM (left) is clear and reflects and highlights characteristic elements of the topography well. Unfortunately, the map based on LiDAR-DEM (right) is practically unreadable due to being too detailed, even though both maps are in the same resolution 10×10m

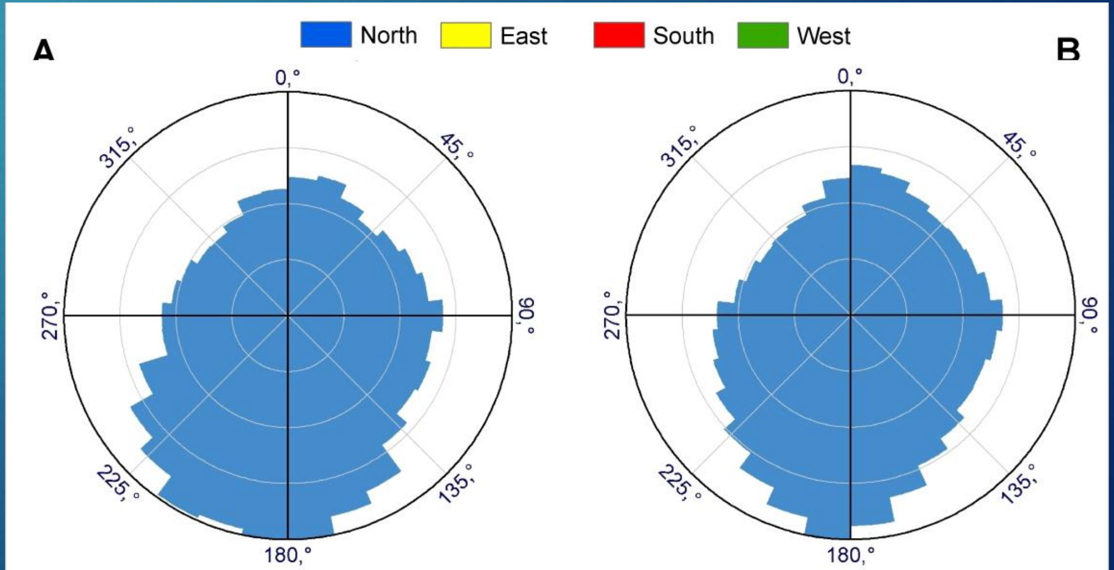


Results - Topo-DEM versus LiDAR-DEM - **basic geomorphometric parameters** (4)

5) Aspect (slope direction). Distribution of the aspects, shows that a map derived from Topo-DEM is much better for analyzing because the image is more generalized (left). LiDAR-DEM aspects introduce too much noise, so the picture is not clear (right).



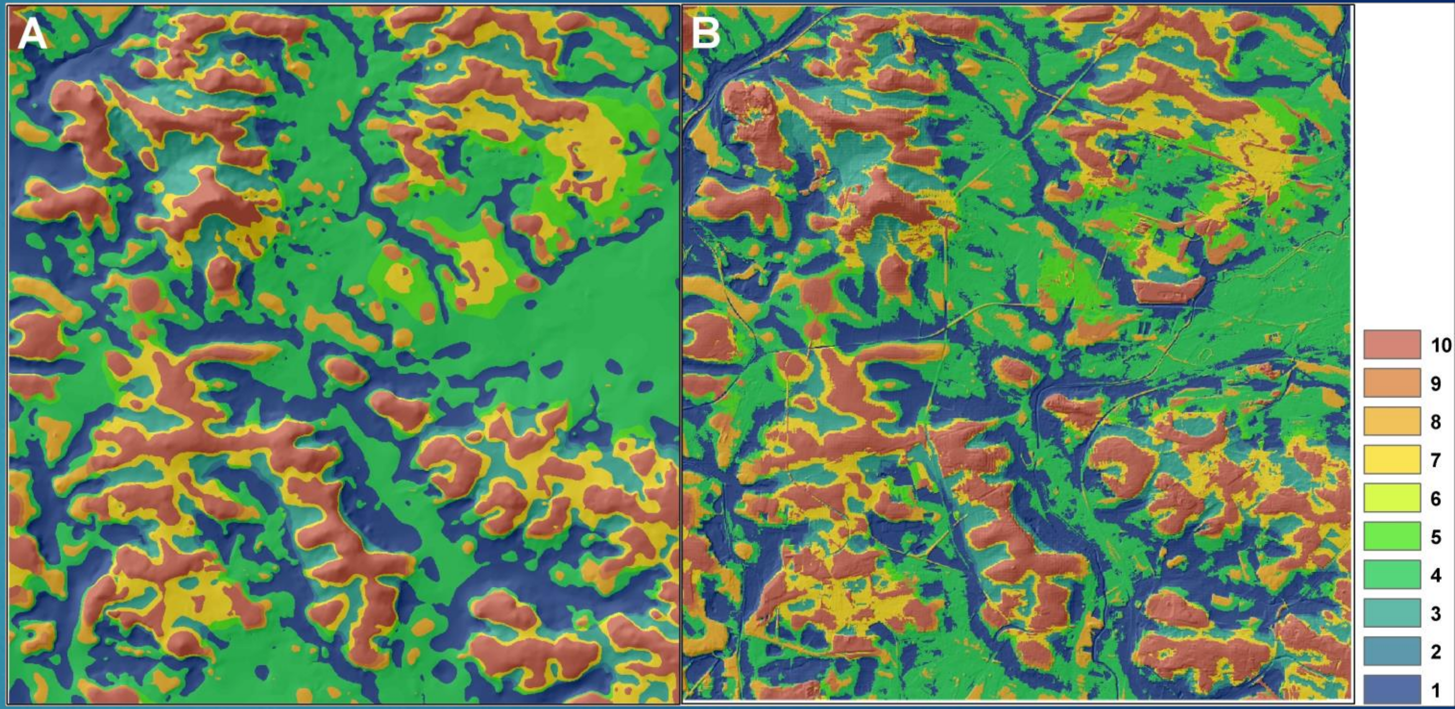
The analysis of the polar plot and the percentage values for particular directions clearly show that the general quantitative-statistical picture is the same for both DEMs. The differences in percentage values between DEMs aspects are very small and range from 0.3 to 1.7%, mean 0.7%.



Generally, one has to state that Topo-DEM deals with this variable very well; this DEM clearly shows the course of the main ridge-lines and river valleys, as well as large areas of slopes with a specific aspect.

Results - Topo-DEM versus LiDAR-DEM - **landform classification** (1)

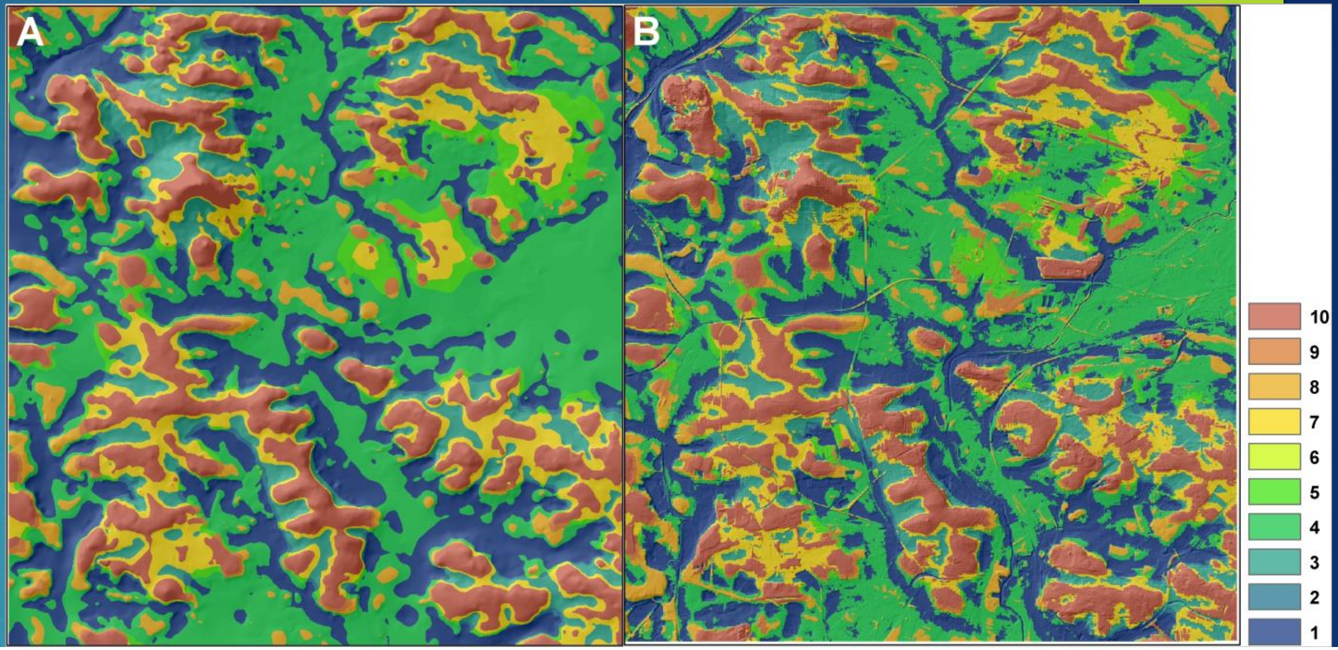
Topographic Position Index (TPI) method was used to landform classification. After various experiments, it was decided to apply 10-class landform classification proposed by Weiss (2001). The best results were achieved with the settings: small neighbourhood = 50 cells, and large = 350 cells. In general, spatial distribution of the main landforms is similar. Classification on the basis of the Topo-DEM is more balanced, slightly generalized compared to LiDAR-DEM. It seems that better visual effects are given by Topo-DEM classification; the image is less overloaded. Although the reality is probably more efficiently reflected by LiDAR-DEM, the reception of the simplified (generalized) image is much better and easier to understand because we focus on dominant elements, avoiding unnecessary details.



Results - Topo-DEM versus LiDAR-DEM - **landform classification** (2)

Moreover, quantitative analysis of landforms showed that results from both DEMs were almost identical. The maximum percentage differences between DEMs are small and range from 0.2 to 3.0%.

As part of the experiment a median filter (window 10×10 cell)was applied to classify LiDAR-DEM classification. The obtained spatial image was very similar to the Topo-DEM results and the compared percentages showed differences ranging from 0.1 to 1.2%.



Class No.	Landform classes	Area of the landforms [%]	
		Topo-DEM	LiDAR-DEM
1	canyons, deeply incised streams	21.9	22.9
2	midslope drainages, shallow valleys	1.7	1.9
3	upland drainages, headwaters	7.7	8.0
4	u-shaped valleys, wide valleys and depressions	29.5	26.5
5	plains small	4.2	3.7
6	open slopes	0.1	0.3
7	upper slopes, mesas	11.2	10.5
8	local ridges, hills in valleys	4.6	6.0
9	midslope ridges, small hills in plains	1.8	2.1
10	mountain tops, high ridges	17.4	18.2
	Total:	**100.0**	**100.0**

Conclusions (1)

1. Elevation accuracy of the analyzed Topo-DEM in 10×10 m resolution corresponds to the precision of the source topographic maps (1:10,000) with the mean error of 1-2 m. These results have been confirmed by GPS RTK measurements (MAE was 0.72 m and RMSE/SD <1 m) and compared with the LiDAR-DEM (MAE 1.16 m, RMSE 1.69 m and SD 1.83 m).

2. LiDAR-DEM with 1x1 m resolution, and even converted to a 10×10 m (downsampling), is great DEM, but sometimes is too detailed for an area of this size (tens of km^2). This had a particularly adverse effect on maps with geomorphometric parameters (slope, curvatures, aspects) and landform classifications. Too much detail caused information overload and blurred the spatial image, making maps unreadable.

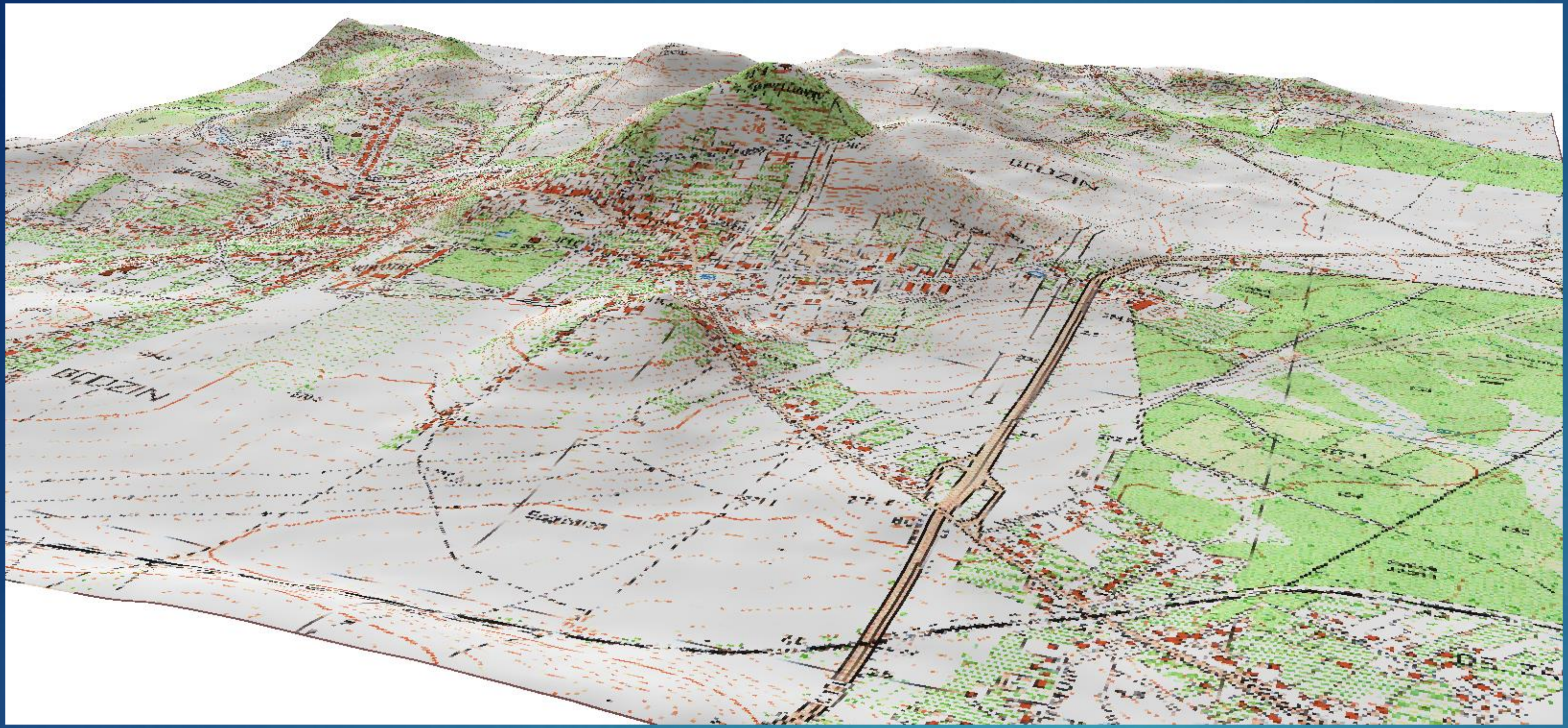
3. A Topo-DEM model coped well with the presentation of topography: it emphasized and reflected the most characteristic and dominant relief features. Maps of derived geomorphometric parameters and landform classification showed statistical and spatial distribution of the relief very well. These results confirmed the significance of geomorphological accuracy in geomorphometric analysis, where correct reflection of the character and leading morphology features more important than absolute height accuracy of a DEM and its detailed conformity with reality.

Conclusions (2)

4. The above informations about Topo-DEMs may be useful when:
– there is no high-resolution DEM derived from LiDAR for the given area, but there are topographic maps that can be used to create a Topo-DEM; such Topo-DEM will be reliable and accurate;
– there is a need to create a DEM of a given area based on historic topographic maps and compare it with the contemporary DEM (i.e. LiDAR), it is important for studies of the areas heavily transformed by man;
– Topo-DEM can be used as reliable data to reduce the errors of freely-available global DEMs (e.g. for some areas in Poland SRTM has a plenty of errors).

So – **Topo-DEM is as good as LiDAR-DEM**?

It depends, but sometimes I think: yes



Szypuła B., 2019. Quality assessment of DEM derived from topographic maps for geomorphometric purposes. Open Geosciences, 11:843-865. DOI: 10.1515/geo-2019-0066

Thank You for your attention!

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