The use of LiDAR in reconstructing lost landscapes of abandoned Ruthenian and German villages in southern Poland

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INTRODUCTION

Due to the post World War II border shifts and the policy of ethnically homogenous nation-states the expulsions and forced displacements of numerous groups of inhabitants took place across the whole Central and Eastern Europe. Particularly, in the mountainous borderlands, the land abandonment turned out to be permanent. The cessation of human activities triggered succession processes and massive land-cover transformations, but at the same time it saved from distortion most of the pre-war man-made landforms and landscape patterns imprinted in the relief. Such processes can be observed in dozens of deserted villages in the Polish Eastern Carpathians and Sudetes, formerly highly populated and inhabited by Ukrainian (Rusyns) ethnic communities and Germans, respectively. Exploration of "hidden traces" in vanished landscapes, which form unique cultural heritage, is one of the main object of landscape archeology.

STUDY AREA

We selected three rural mountain regions that experienced forced displacements of the majority of native populations: Bieszczady Mountains, Przemyśl Foothills (both in the Carpathians), and Śnieżnik Massif (in Eastern Sudety Mountains). The displacements resulted from the World War II and the post-war border shifts, as well as from the post-war depopulation associated with natural and socio-economic factors. Each region is represented by one village, which was subject to the lowest human impact over the last 70 years – Caryńskie, Borysławka and Rogóżka villages, respectively (**Table 1**).

MATERIALS AND METHODS

LiDAR data

We used classified point clouds (LAS 1.2 format), produced within Poland's nationwide project entitled 'Information System for Protecting the Country against extraordinary threats' (ISOK; **Table 2**). Points belonging to 'Ground' and 'Key points' classes were used to generate DEM with a resolution of 0.5 m (TIN natural neighbour sampling, no thinning). The conversion was made in ArcGIS 10.2.2 with LP360 Advanced extension dedicated to LiDAR-derived point clouds. Next, the Sky-view factor (SVF) visualization was generated (16 directions, 10 m range, without noise reduction) in the Relief Visualization Toolbox software.

Table 2. Airborne laser scanning metadata (ISOK)

Parameter	Value
Scan angle	≤ ±25°
Strip overlap	20-30%
Laser beam footprint	≤ 0,50 m
Point density in a single strip	4 points/m^2
Altitude accuracy	≤ 0,15 m
Horizontal accuracy	≤ 0,50 m
Registration of multiple reflections	minimum 4 echos

AIMS OF THE STUDY

- to detect, by the use of airborne laser scanning (ALS), patterns of former land-use types, landforms, and other marks of historical human impacts left before the displacement and still imprinted in the microtopography of the areas;
- to critically assess the value and application opportunities of national LiDAR dataset in reconstructing of pre-war landscape features and patterns of abandoned and afforested mountainous villages of southern Poland.

Table 1. Characteristic of the study sites

Village	Region	Coordinates	Area [km^2]	Foundation century	Abandonment period	Number of inhabitants/farms		Displaced population
						1930s	2019	
Caryńskie	Bieszczady Mountains	49°09′59″N 22°37′06″E	17,0	16th	1946	503/65	0/0	Boykos
Borysławka	Przemyśl Foothills	49°38′41″N 22°36′43″E	7,9	15th	1945	810/140	0/0	Ruthenian highlanders
Rogóżka	Śnieżnik Massif	50°17′17″N 16°48′38″E	3,6	14th	1960s	124/31	0/0	Germans

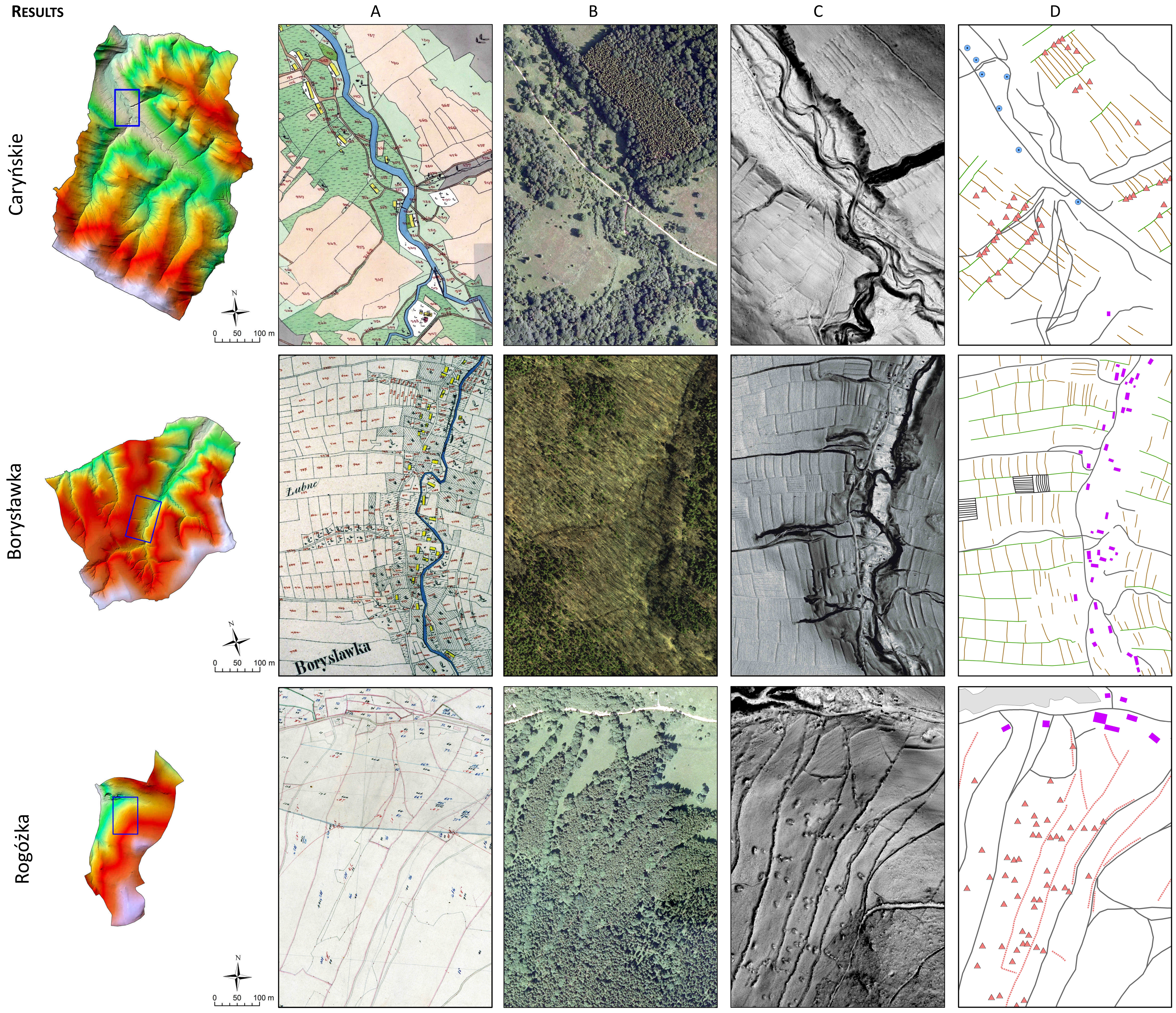
Other sources

- Primary: old cadastral maps (Austrian 1:2880 and Prussian 1:5000) served as reference spatial data for mid-19th century land use.
- Supplementary (archival and actual): descriptive cadastral data, civil and military topographic maps, aerial images, orthophotos, regular photographs, etc.

Field work

LiDAR data verification, particularly: morphometric measurements of old roads and in-field terraces, GPS location and mapping of settlement remnants and selected man-made features, evaluation of the state of their preservation, interviews with senior members of the local community and employees of the State Forests National Forest Holding, photographic documentation.

RESULTS



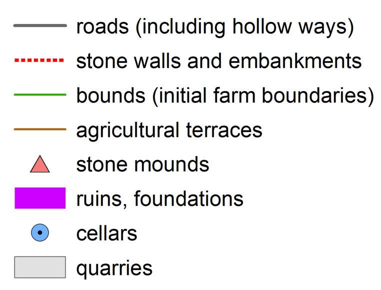


Figure 1. Fragments of 3 representative villages: A – mid-19th century cadastral maps (original scale 1:2880-1:5000); B – orthophoto showing present landscape/land cover; C – Sky-view factor visualization of the LiDAR-derived DEM (pixel size 0.5 m); D – interpretation of the microtopographic features

Table 3. The usefulness of LiDAR data in detection of microtopographic man-made features created before World War II and still present in the study areas

Landscape features	Bieszczady Mts. (Caryńskie)	Przemyśl Foothills (Borysławka)	Śnieżnik Massif (Rogóżka)
Roads (*including hollow ways*)	***/**/*	***	***/**
Agricultural terraces	***	***	***
Ploughing traces	***	***	***/*
Earthworks marking parcel and/or administrative boundaries (*stone mounds, walls and embankments; escarpments*)	***	***	***/**
Remnants of settlements (*ruins, foundations, cellars, wells, settlement terraces etc.*)	*	***	***/**/*
Earthworks related to mining (*quarries, stone mounds*)	lack	lack	***

*** clearly visible on LiDAR data; ** moderately visible on LiDAR data, additional materials/field surveys are necessary; * hardly visible or not detectable on LiDAR data; '/' means a spatial diversity of the readability of landforms in different parts of the village

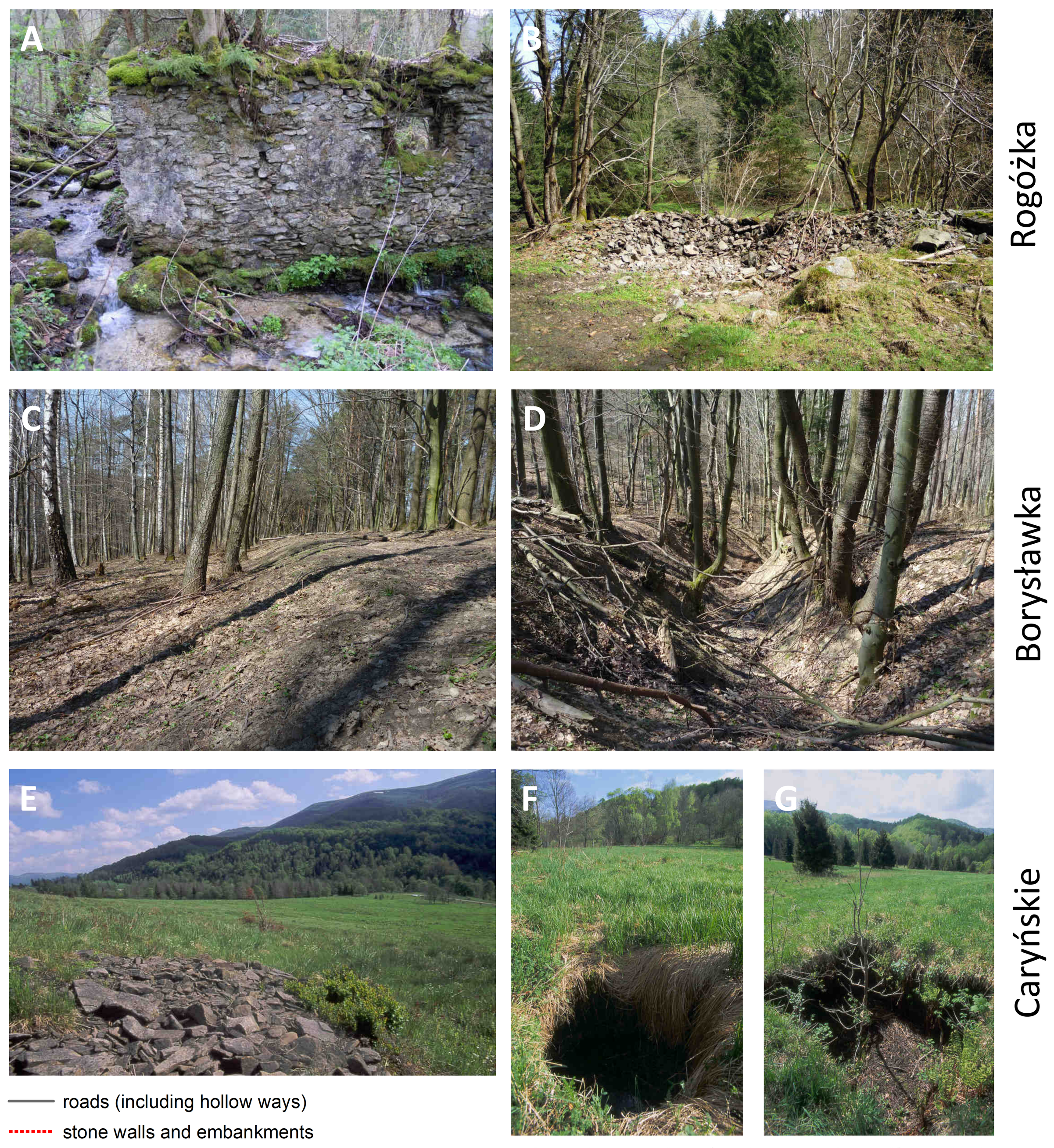


Figure 2. Examples of anthropogenic landforms in the abandoned villages: A – ruin of a house, B – stone embankment, C – agricultural terrace, D – hollow way, E – stone mound, F – well, G – cellar.

DISCUSSION

LIDAR added value

- A high resolution model of land surface, including places under vegetation cover (only a very dense vegetation is a limitation factor).
- An image from a bird's eye view helps perceive and interpret much more complete past spatial patterns (at landscape scale, not only at single site scale).
- ALS allows to record ploughing traces (invisible at the ground surface during field-work), including pre-war traces currently under the tree canopy or under the turf; this is an unique opportunity to get to know the specificity of the former farming systems.
- ALS allows to reconstruct the historical spatial patterns of villages and land ownership (cross-checked with cadastral data).
- In places where human impacts completely ceased, LiDAR gives the opportunity to see the old village pattern as it was just before abandonment, because the landscape features have been almost 'frozen'; such scale and degree of details is impossible to obtain by any other cartographic source or field research.
- Lidar point cloud processing tailored to individual needs enhances interpretation possibilities compared to LiDAR-derived end products available online (usually shaded DEMs), e.g. the road ruts and ploughing traces have only become visible on DEM with the resolution higher than the default 1 m (**Fig. 3**).

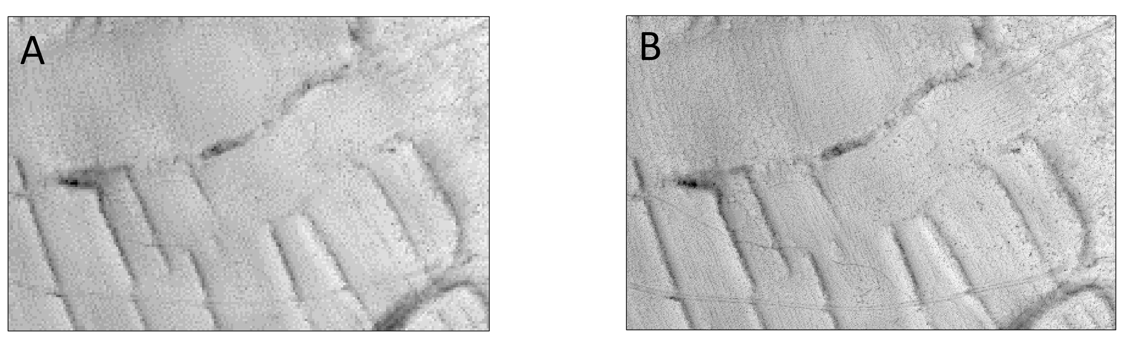


Figure 3. Visibility of road ruts and ploughing traces in the Sky-view factor visualization: A – 1.0 m resolution (invisible), B – 0.5 m resolution (visible). Further reducing the size of the pixel is not advisable, because the number of pixels per 1 m^2 should not exceed the number of points per 1 m^2 (in our case – 4 sizes 0.5×0.5 m)

LIDAR limitations

- Creates the temptation to forget that LiDAR-based visualization is a model of reality, and not the reality itself.
- The value of LIDAR-based visualization is influenced and may be biased by multiple scanning-related factors: time of the year and day, weather conditions, flight and scanning parameters, etc.
- In a long chain of transformations: from electromagnetic echo to DEM visualization (light signal => electric signal => raw point cloud => classified point cloud => triangle grid => raster model => shading) every subsequent 'chain link' may be a source of errors or uncertainty.
- Limitations of the scanner expressed by the multi-target resolution (MTR) value; for example when earthworks were covered by low and dense vegetation, there is no possibility of obtaining an accurate shape of the Earth's surface, even if some of the pulses reach the ground. In such cases, the nominal ranging accuracy of 2 cm (for single returns) increases up to 60 cm.
- A choice of data processing technique is a critical step – algorithms and classification / interpolation parameters can significantly affect the resulting image, highlighting some aspects, and blurring others (**Fig. 4**).
- A problem of a proper classification; for example in the case of the 'Ground' class points some objects may be removed and assigned to other classes not used to create DEM (e.g. remnants of settlements assigned to the class 'Building', cellars and wells to the class 'Low Point', and dugouts to the class 'Low and Medium Vegetation').
- Some features (such as overgrown, not hollow roads), can only be identified during field work.

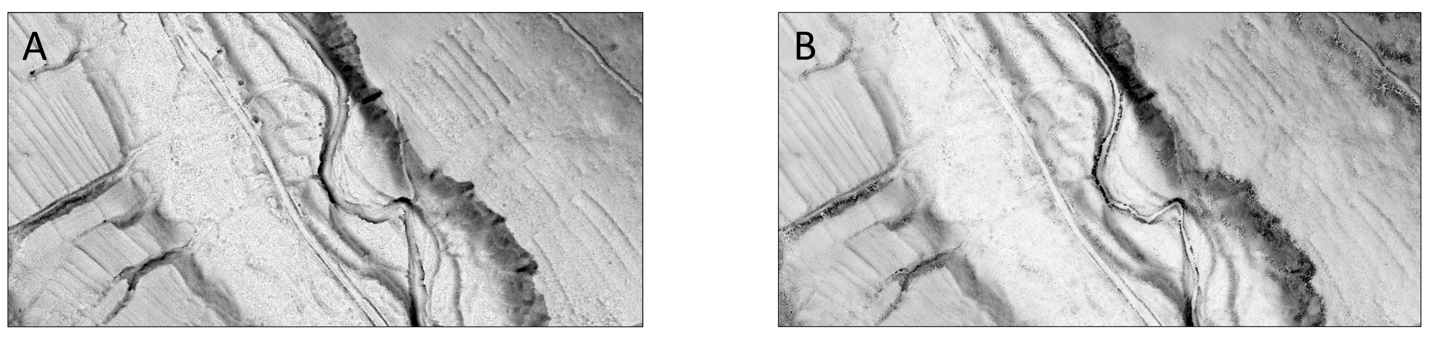


Figure 4. Differences between Sky-view factor visualizations (both 0.5 m resolution) based on two methods: A – Triangulated Irregular Network (TIN); B – Inverse Distance Weighted (IDW). In the case of IDW, the visualization is generally more blurred, the details disappear within the flat bottom of the valley, the road ruts and ploughing traces become invisible, and unnatural artifacts appear in places more difficult to interpolate (lower density of ALS points in 'Ground' class)

CONCLUSIONS

- Point clouds modeling based on own designed parameters specific to the study area brings a significant added value to the data interpretation phase, and enhances final research conclusions, compared to the usage of Lidar end products available online.
- In villages abandoned after World War II the past landscape pattern visible on mid-19th century cadastral maps is still well conserved in the relief, and detectable by LiDAR. In places where human activity ceased after displacement of inhabitants, landscape is like palimpsest – the microtopographic man-made features are very time-resistant, however a precise interpretation of historical stratification is possible only when LiDAR technology is integrated with other data sources and field surveys.
- Field verification is necessary in order to: (a) create an image interpretation key that will help explain what landscape features correspond to LiDAR-based visualization; (b) determine the state of preservation / degradation of the landform (e.g. small landslides within escarpment of terraces are not visible on DEM), (c) avoid interpretation errors (e.g. some 'mounds' visible on DEM turned out to be piles of decomposing branches formed as a result of forest maintenance activities).