GIS Odyssey Journal

2021 • Volume 1 • Number 1

https://doi.org/10.57599/gisoj.2021.1.1.177

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ANALYSIS OF THE POSSIBILITY OF USING ARCHIVAL MAPS AS A SOURCE OF ELEVATION DATA

Abstract: One of the most popular sources of elevation data covering the most of the Earth's surface with spatial resolution of up to 30 m (1 angular second to be exact) is the SRTM model. This terrain model has two main disadvantages: it covers the area of the Earth between the parallels 54°S and 60°N only, and in some mountainous and desert areas there are gaps (voids) in the data. Additionally, it may not be suitable for more detailed visualization and analysis due to their limited accuracy. Therefore, the paper attempts to find an alternative source of elevation data. One of them may be archival maps, on which the terrain is presented by means of contours. By vectorization of such lines and adding respective attributes they can serve as a base for building digital terrain models. Examples of such maps are maps created in the period before World War II by Polish Military Geographical Institute (WIG). Although newer topographic maps or even more accurate spatial databases exist, it is assumed that as official materials WIG maps were not covered by copyright, so they are in public domain, just like SRTM. Conducted research and literature studies have shown that the issue of using contours extracted from archival topographic maps is not unambiguous. The lack of reproducibility in the results obtained does not allow making clear recommendations on the feasibility of using archival maps. Using a contour drawing as the sole source of elevation data, without any control, should be considered risky. On the other hand, it seems possible to use them as supplementary and perhaps refining material, but only in places where consistency with other data can be observed.

Keywords: contours, Military Geographical Institute, open geodata, SRTM, vectorization

Received: 14 June 2021; accepted: 2 August 2021

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Introduction

In all areas of scientific research dealing with the Earth's surface, data describing landforms such as elevation, slopes, or exposures are essential. A digital representation of a portion of the Earth's surface is called a Digital Elevation Model (DEM) (Weibel, 1991). There are many datasets, including those with global coverage, from which the above parameters can be determined. The most commonly used is the SRTM model, which can serve as a source of elevation data covering most of the Earth's surface with a spatial resolution of up to 30 m (1 angular second to be precise). Its advantage is relatively stable accuracy (Yang et al., 2011), but it is popular also due to the fact that it is in the public domain (OpenStreetMap Wiki, 2021).

The resolution was originally limited to 90 m (3 angular seconds) for areas outside the United States (Pierce et al., 2006) and the so-called SRTM-3 to this day is the only fully open dataset, as no registration (creating an account) or login to the data sharing server is required to download the files.

Data to build this model were acquired in 2000 from aboard the Endeavour space shuttle during the so-called Shuttle Radar Topography Mission (hence the abbreviation SRTM), the purpose of which was interferometric radar scanning of the Earth's surface (Michalak, 2004). The measurement equipment installed on the shuttle consisted of a 60-meter mast and associated two parallel measurement systems operating in the X and C bands, respectively (Farr et al., 2007). The terrain model obtained by processing these data was successively made available for subsequent areas starting from 2003. A single elevation dataset stored in HGT format covers a “square” of 1 angular degree. This terrain model has two main disadvantages: the scanning covered the area of the Earth between parallels 54°S and 60°N only, and in some mountainous and desert areas there are gaps in the data due to obscuration of some terrain parts or poor reflection of the signal from some surfaces (Dowding et al., 2004). Therefore, the model has been refined many times and by different institutions. From the original source, version 3 is now available, the development of which focused mainly on filling gaps. Mostly data from the “competitive” ASTER GDEM2 project was used for this purpose (Tadono et al., 2012).

A different approach was used by the Consortium for Spatial Information (CGIAR-CSI) of the Consultative Group for International Agricultural Research (CGIAR), which primarily used spatial interpolation tools to fill in the gaps using the method described in (Reuter et al., 2007). For this purpose, the original one-degree “tiles” were combined into larger 5 by 5 degree files.

The datasets made available from the two mentioned above sources contain elevations expressed in meters, measured relative to the EGM96 geoid, and spatially referenced to the WGS84 ellipsoid in the geographic coordinate system.

In another form, the SRTM model can be downloaded from the Global Land Cover Facility (GLCF) website (USGS, 2006). In this institution, ENVI software triangulation algorithms were used to fill in the gaps, and the size of the “tiles” was matched to Landsat satellite scenes while using UTM projection.

According to the author of the website (de Ferranti, 2014), the best alternative data source to SRTM are topographic maps, especially for mountainous areas and particularly if they have been drawn from measurements made in the field. He points specifically to Russian military maps recognizing that, with few exceptions, the contour lines are correctly drawn on them and their course is more accurate than that obtained by interpolation methods.

Poland can also be proud of its valuable cartographic works. Particularly appreciated are maps published in the interwar period by the Military Geographical Institute (WIG) (Sobczyński, 2013). Based on an analysis of the materials left over from the invaders, conclusions about the use of maps in World War I, as well as the needs of the economy and the army and the capabilities of the WIG, it was then decided to first issue a map at a scale of 1:100,000 (the so-called tactical map of Poland). All 483 sheets of this map were prepared and published by June 1939. Some of them, the so-called fourth model, in force since 1931, can still serve as an example of precise drawing, aesthetic coloring, and high printing quality.

WIG maps continue to be relevant source material (Kaim, 2009; Warcholik, 2005) despite the fact, that newer topographic maps or even more accurate spatial databases exist. From the point of view of their potential use cases, it is important that, as official materials, they were not covered by copyright (however there is no clear legal interpretation on this issue). Thus, they are in the public domain, just like SRTM. For this reason they were chosen by the Author as the object of research, which aimed to investigate whether terrain models built on the basis of WIG maps in scale 1: 100,000 may have a greater accuracy than available free models with spatial resolution of about 100 meters.

Material and methods

An area north of Sanok in Subcarpathian Voivodeship was selected for this study (Fig. 1). It is covered by two sheets of contemporary orthophotomap M-34-93-A-b-4-3 and M-34-93-A-b-3-4 and by a digital terrain model recorded in the form of a regular grid of height points with an interval of 1 m – hereinafter referred to as a detailed or accurate model. Both datasets were obtained from the Polish state geodetic and cartographic resource. This area is also depicted on the sheet of the Military Geographical Institute (WIG) tactical map of Poland labeled "PAS (row) 50 SŁUP (column) 34 SANOK" (WIG, 1937b) (Fig. 2).

From the remaining off-frame description, one can learn that this sheet, published in 1937, was compiled between 1936 and 1937 based on a detailed map at a scale of 1:25,000 from 1935. According to Sobczyński (2013), for maps published after 1931, the basic material was field-verified maps at a scale of 1:25,000 (WIG, 1937a) and original plane table surveys made at a scale of 1:20,000 by the Topographic Division of the WIG (WIG, 1936). The sheet in question is one of 40 issued since 1932 in the tourist version, which were printed in five or six colors allowing, among other things, the relief to be shaded in grayish purple to create an impression of spatiality. They were enriched with information about mountain shelters, hiking trails, borders of nature reserves, natural parks, natural monuments, battlefields, and the like.

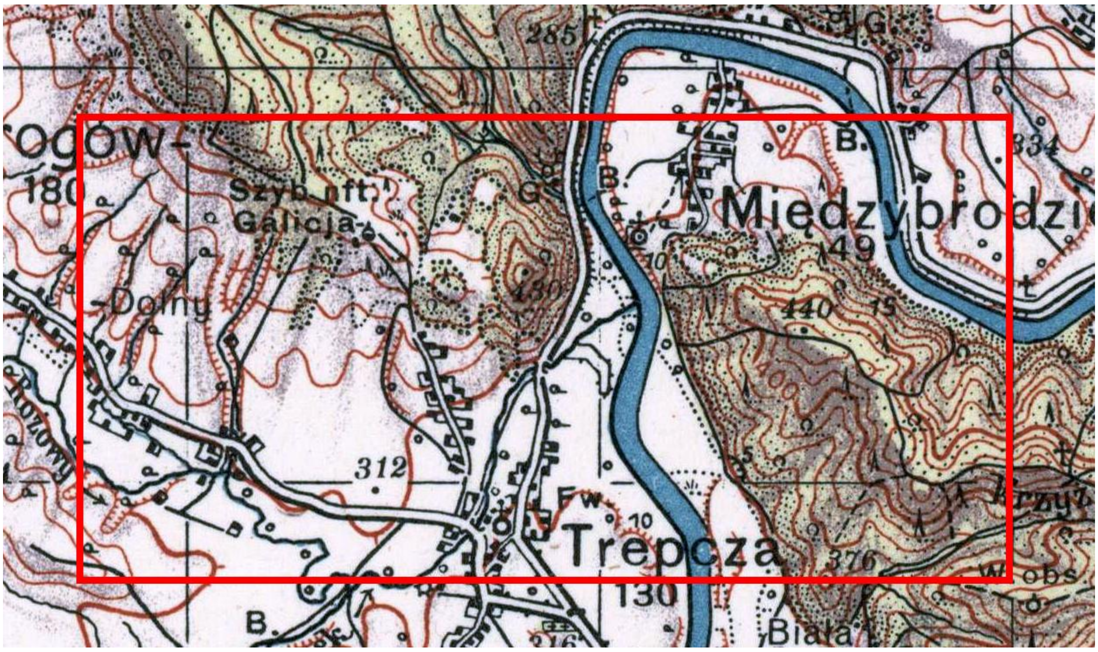

Fig. 1. The study area (red rectangle) presented on a background of the sheet of the Military Geographical Institute (WIG) tactical map of Poland selected for the research
Source: WIG, 1937b

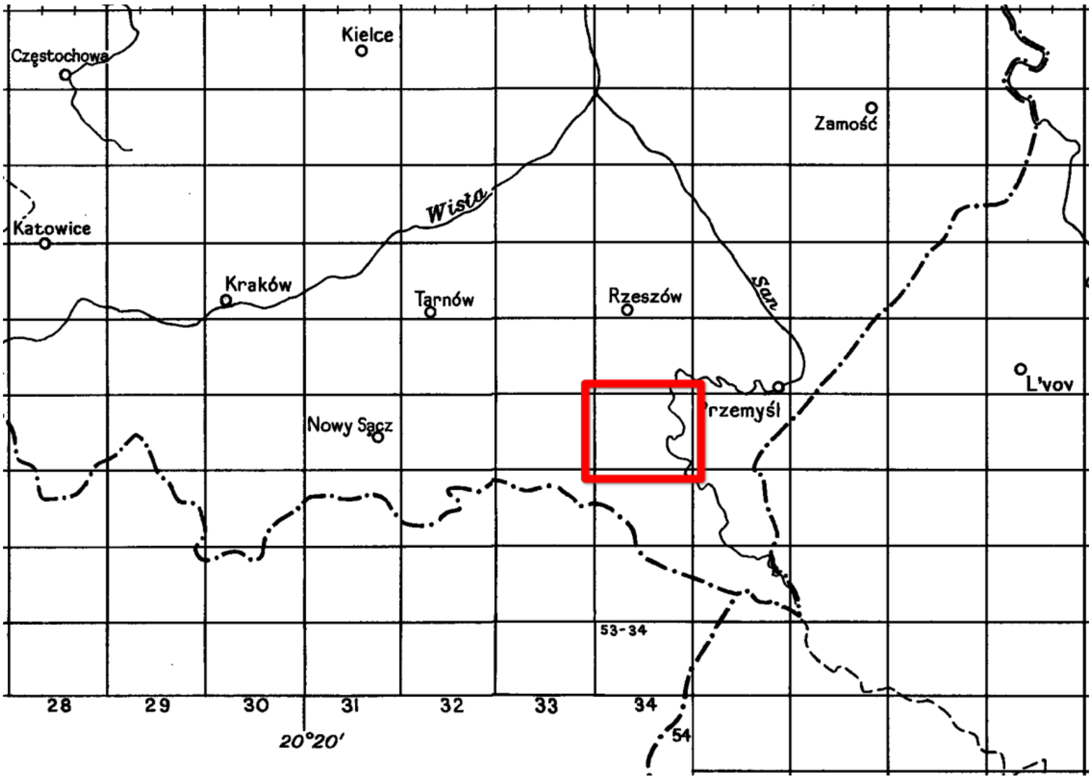

Fig. 2. The red rectangle indicates the area covered by the Military Geographical Institute (WIG) tactical map of Poland sheet selected for the research
Source: Poland 1:100,000 with international boundaries (1938 & 1953)

One of the main problems related to the use of WIG maps is an issue of spatial reference (georeference). According to Kozakiewicz (2011) and Panecki (2014), when calibrating WIG maps based on the geographic coordinates provided on them or based on a kilometer grid, one has to expect larger errors than with other maps. This is mainly due to the inconsistencies between the remaining triangulation systems of the invaders, constituting the framework of these maps. Therefore, it was decided to perform a transformation based on characteristic points in the form of road intersections, assuming that they have not changed significantly in over 80 years. Originally, the contemporary base on which the transformation was to be based was to be OpenStreetMap, probably the most comprehensive source of open geodata in the world. However, the QGIS software used for this purpose (QGIS.org, 2021) was found to have issues with correctly displaying the map image from this source. When zooming or panning the image, the position of the background changed in relation to other map elements. Eventually a Web Map Service (WMS) presenting the transportation network, available through Geoportal (a central node of the Spatial Data Infrastructure in Poland), was used.

Initially, four control points near the analyzed area were selected and a first-degree polynomial transformation was applied (Jaskulski et al., 2013), which, however, resulted in large differences at the edges of the sheet. Therefore, additional points were added at those locations and the transformation method was changed to a second-degree polynomial transformation (however, keeping in mind the danger of using too high degrees of polynomial), all the time monitoring the magnitude of the residual error and eliminating control points generating too high error, which could indicate the instability of a given point. Finally, the error of about 10 m and satisfactory visual consistency with the reference background (contemporary road network) were obtained.

Having the image of the map placed in a proper location, all the contour lines visible in the selected area were vectorized in the form of two-dimensional polylines, saving the height in a column created for this purpose in the attribute table. From the off-frame description of the WIG map sheet it was possible to find out that the main contour lines were drawn every 20 m, with the contour lines representing heights multiple of 100 m being distinguished by bold lines.

On the basis of the height data collected this way, a digital elevation model was built. Based on the conclusions from the paper (Cichociński & Basista, 2013), terrain models were generated in the QGIS program using three methods: Multilevel B-Spline, Thin Plate Spline (TIN) and r.surf.contour. The quality of the obtained models was first verified by creating a shaded relief image (hillshade) on their basis. The initial visual assessment showed that the results were disappointing. In case of TIN, triangles were visible (Fig. 3), in model obtained with the use of Multilevel B-Spline method puzzling depressions appeared at the ends of contour parts (Fig. 4), whereas r.surf.contour method (Fig. 5) did not cope with breaks in contour lines resulting from ravines.

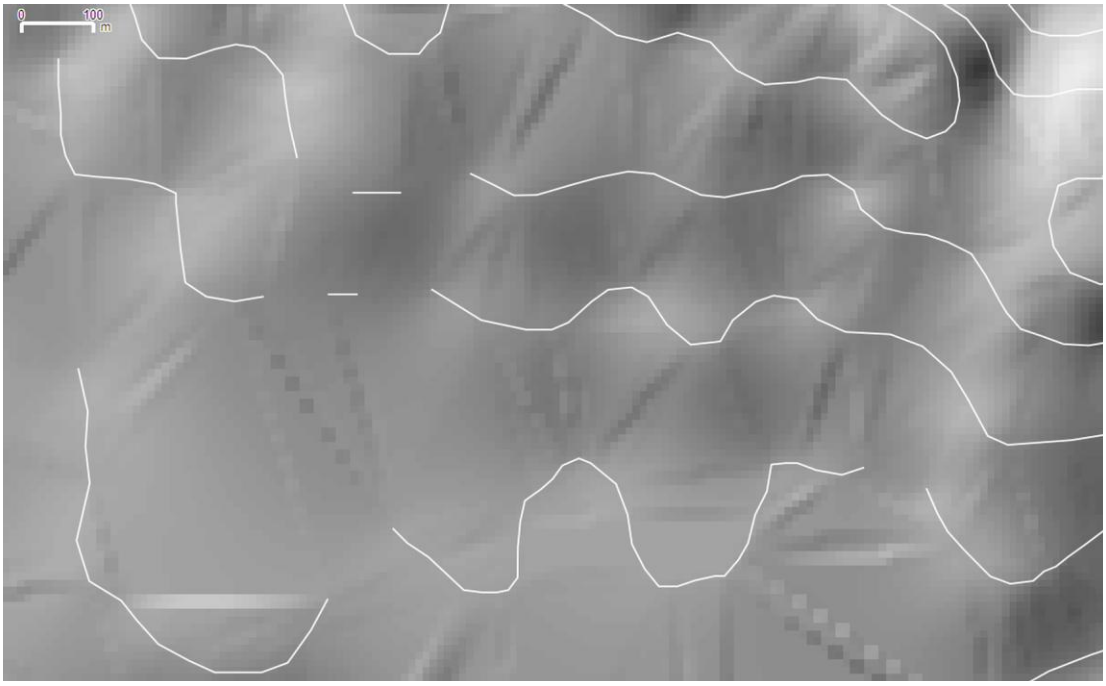

Fig. 3. Errors in digital elevation model obtained by Thin Plate Spline (TIN) method
Source: own study

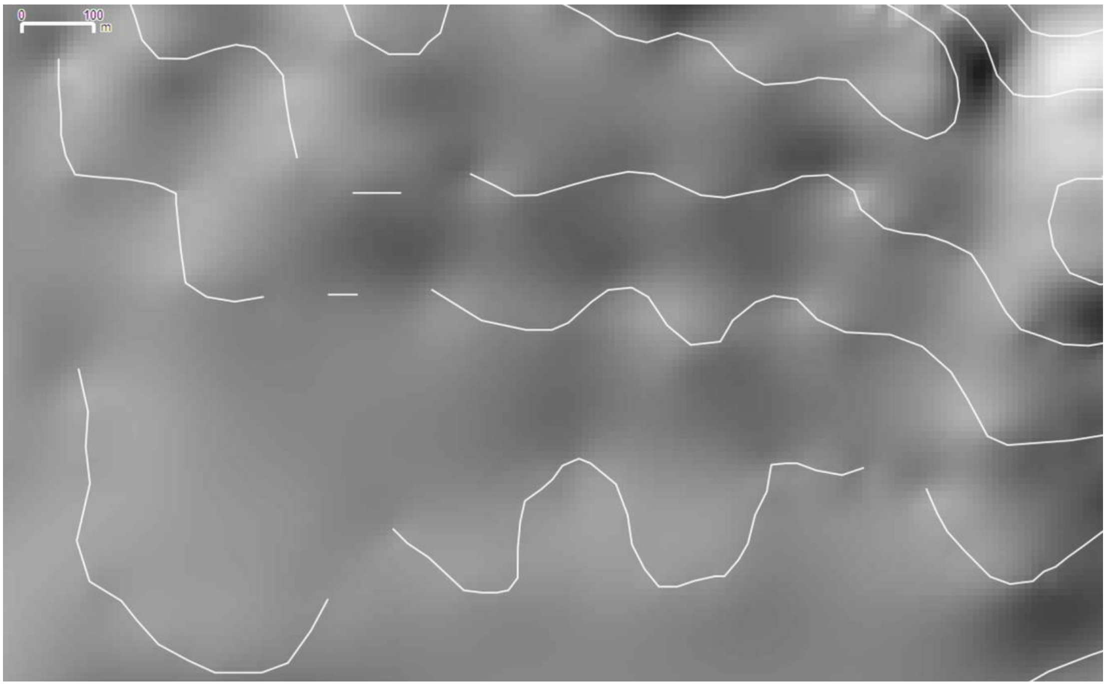

Fig. 4. Errors in digital elevation model obtained by Multilevel B-Spline method
Source: own study

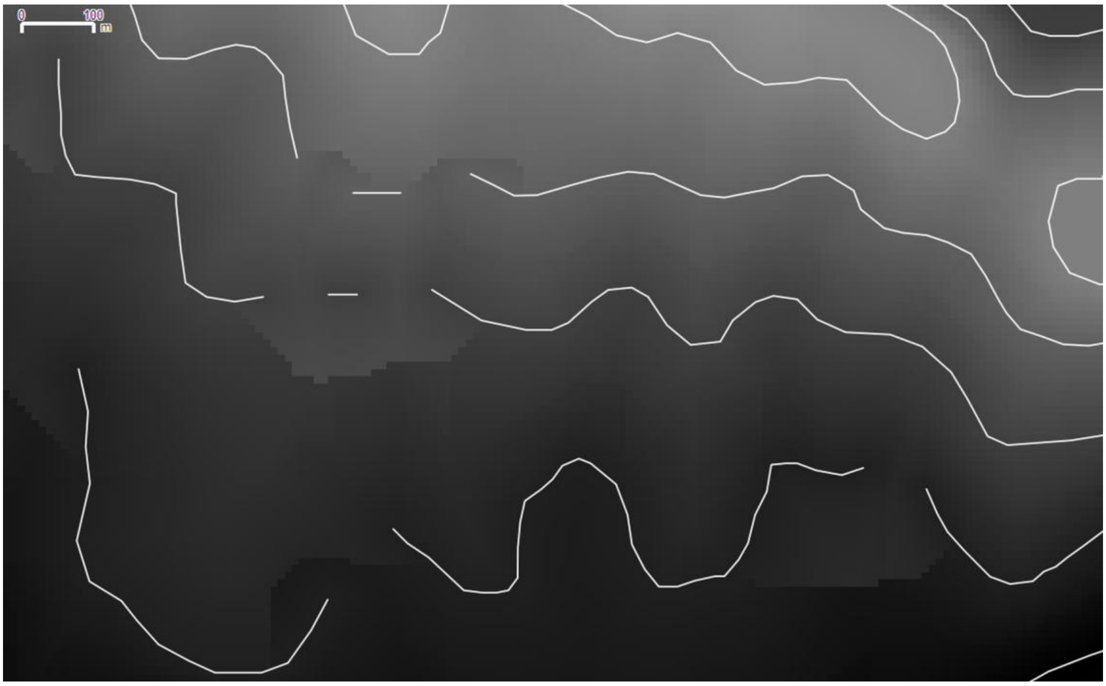

Fig. 5. Errors in digital elevation model obtained by r.surf.contour method
Source: own study

The research began by verifying the three SRTM models covering the study area obtained from the websites: “original”, CGIAR and GLCF. After loading them into the QGIS program, a problem was noticed, consisting in a slight (by about ½ pixel) shift of these models in relation to each other, most probably resulting from different interpretation of the location of the point of attachment of the whole image (bottom left corner) – whether it is located in the corner or in the center of the pixel located in the bottom left corner. The “original” model had the greatest similarity with the detailed model and it was the one that was eventually used in further analyses.

In order to increase the comparability of the models (also to allow for some operations), the SRTM raster was transformed to the PL-1992 (EPSG: 2180) coordinate system and all rasters were given the same pixel size. Spatial resolution of 10 m was adopted based on the conclusions of the paper (Zhang & Montgomery, 1994) stating, that a grid of this cell size is optimal for the simulation of geomorphological and hydrological processes, keeping in mind that file sizes increase with increasing resolution. Also, Thompson et al. (2001) suggest that a higher resolution of DEM may not be necessary to generate useful models for soil analysis.

Results and discussion

The first step of the main analyses was to compare the course of contour lines that were generated from the obtained models with a 20 m interval (consistent with the WIG map). The visual assessment applied also in this case showed that in areas of low heterogeneity, high coherence of contour lines obtained from all three sources can be observed (Figure 6 in the lower part). In such places, discrepancies between models (presented in Figure 7 in the form of a graph of differences plotted along a short Wshaped contour line obtained from the WIG map) were at the level of single meters. On the other hand, when the terrain started to become more complicated, the consistency of the general trend of the contour lines could be observed in some places, whereas minor terrain forms, such as ravines, started to be not reflected on the less accurate models (Figure 6 in the upper part). The greatest discrepancy can be seen in mountainous terrain. There is a complete mismatch between the vectorized contours and those obtained from the other two models (Fig. 8).

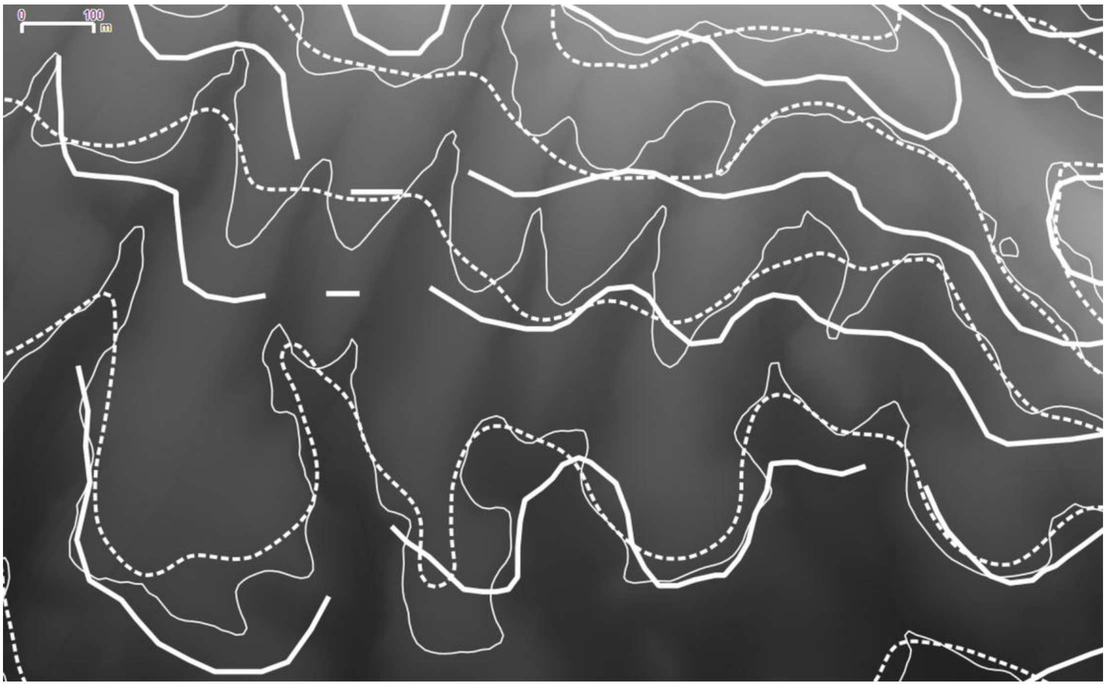

Fig. 6. Comparison of contour lines obtained from three sources: accurate model (thin line), SRTM (dashed line) and WIG map (thick line) in low diversified terrain
Source: own study

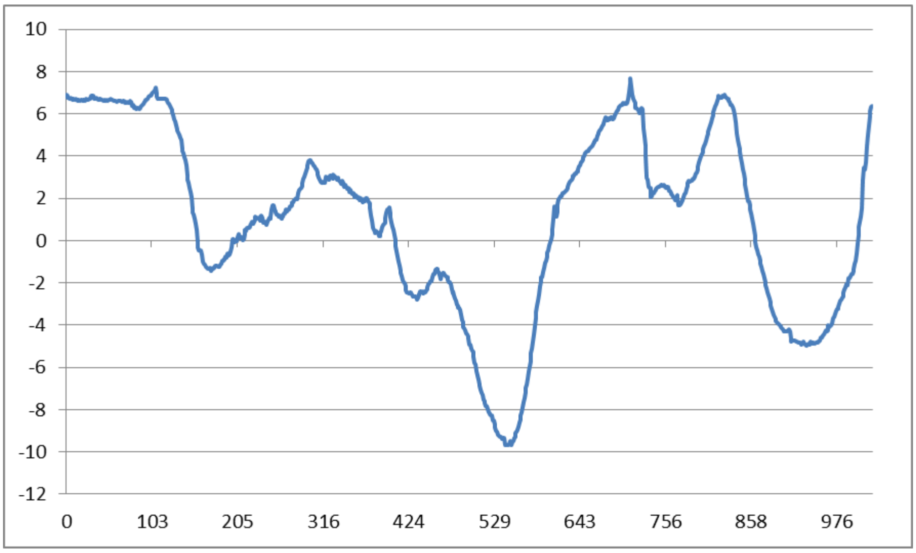

Fig. 7. Longitudinal section along a contour line that follows an accurate model
Source: own study

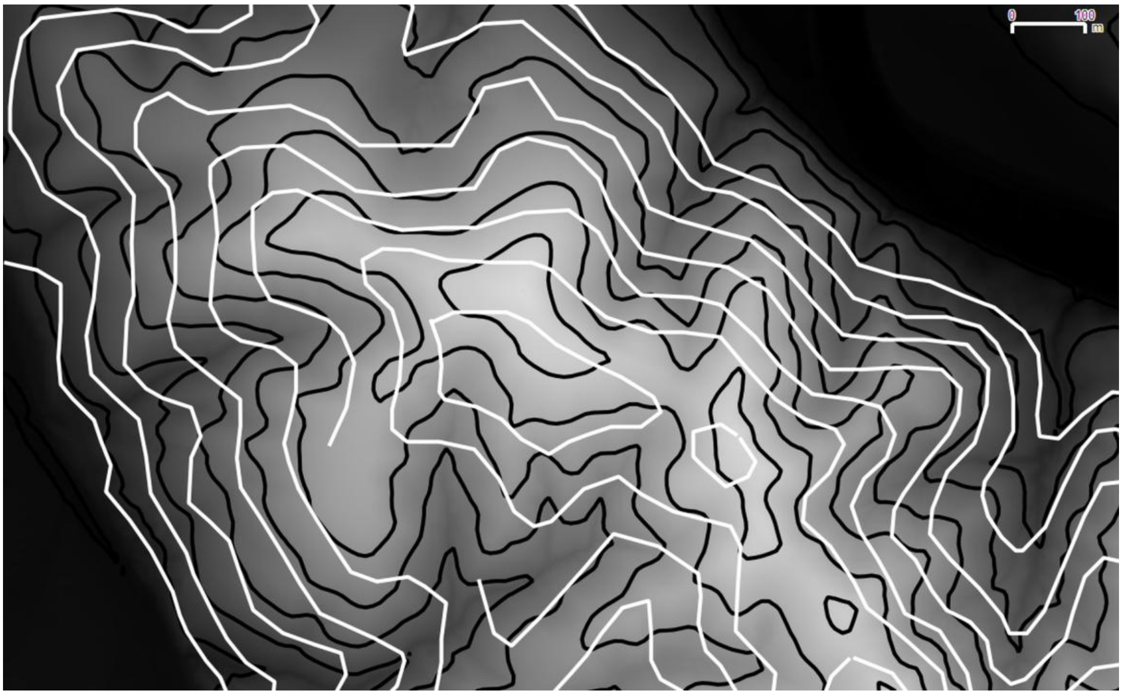

Fig. 8. Comparison of contour lines obtained from two sources: accurate model (black line) and WIG map (white line) in mountainous terrain
Source: own study

Fig. 9. Comparison of contour lines obtained from WIG map to accurate model
Source: own study

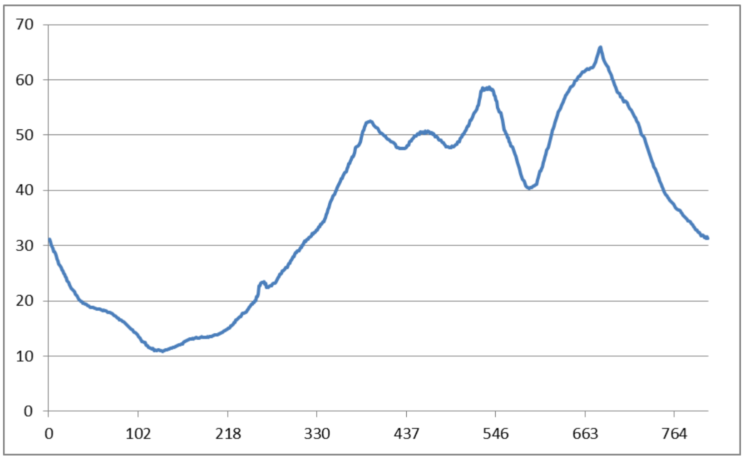

Fig. 10. Longitudinal section along a contour line that differs from the accurate model
Source: own study

However, the chaos in the image makes an effective assessment of errors impossible. Therefore, the WIG contour lines were presented on the background of the detailed model itself. Based on Figure 9, it can be concluded that these contour lines quite faithfully represent the larger terrain forms, but it is impossible not to notice that the peak visible in the middle is shifted by about 100 m. This causes the height differences determined along the centrally located, the highest contour to exceed 60 m (Fig. 10).

Conclusions

The conducted own research and literature studies have shown that the issue of using contour lines extracted from archival topographic maps is not unambiguous Description of applications presented by Gamache (2004) can be considered as a confirmation of their usefulness. However, the experiments described above suggest that the key problem is the quality of the source material. WIG maps were made using the plane table surveying method (WIG, 1936), which had two limitations. Firstly, measurements were taken in relatively small areas with a radius of 600 m, and although it was recommended to check the interconnectedness of the different areas, it was probably inevitable that there would be some inaccuracies in the location of objects and landforms. Secondly, the use of this method, due to visibility problems, was very limited in wooded areas. This may have been the main reason for the observed errors.

Lack of reproducibility in the obtained results does not allow formulating definite recommendations regarding the possibility of using archival maps. Using contour drawing as the only source of elevation data, without any verification, should be considered as risky. Additionally, as can be seen, the contour lines extracted from the map are not at all more detailed than the contour lines generated from the SRTM model and thus do not contribute anything beyond what can be obtained from the SRTM model. On the other hand, it seems that it is possible to use them as complementary and perhaps detailing material, but only in places where consistency with other data can be observed.

Acknowledgements

This work was prepared within the scope of the research funds from the AGH University of Science and Technology in Krakow, no. 16.16.150.545.

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