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Georectification of the Historical Geological Map of Bosnia and Herzegovina: Effectiveness Evaluation of Different Approaches

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Abstract: The Geological Overview Map of Bosnia and Herzegovina, at a scale of 1:200,000, is the first comprehensive and detailed geological map meticulously created for the entire country. This paper examines the mathematical and geodetic basis of the map and evaluates its positional accuracy. A method was developed to compute coordinate corrections for arbitrary points based on the differences between the Austro-Hungarian and Yugoslav triangulations, in order to determine the position of any point on the old geological map with respect to the current Bosnian-Herzegovinian state coordinate system. After resolving the issues related to map projection, mathematical and geodetic foundations of the map and coordinate systems, the georectification procedure was applied to the map scan. The results show that the TPS transformation effectively minimizes geometric distortions caused by scanning errors, deformations of the map's base material, and systematic errors from the original map elaboration. After applying the georectification, most remaining positional distortions were attributed to random errors.

Keywords: accuracy assessment; geological map; georectification; transformation; triangulation

1 INTRODUCTION

Maps are reliable records of the space and time in which they were created, making them a valuable source of data for various spatial analyses. In this context, historical cartographic materials—such as old military maps, cadastral maps, topographic maps, thematic maps, and other specialized maps—are essential for retrospective analysis of past landscapes [1]. For this reason, maps can be seen as a reflection of past eras and serve as an important part of global cultural heritage [2]. A geological map is a graphical representation of the terrain, including the age of rocks, their composition, interrelationships, and other significant geological phenomena. Old geological maps are invaluable sources of information about the state of geological knowledge at a specific time. Integrating historical geological maps into a GIS database enables the analysis and comparison of past geological data and knowledge with contemporary findings [3]. The study of old geological maps is extremely important, not only for their historical significance in the development of geological mapping but also from a practical perspective [4].

The first map to visually represent actual geological field observations for the territory of Bosnia and Herzegovina (B&H) was created by Ami Boué. His geological travels across the Balkan Peninsula between 1836 and 1838 brought him to Bosnia and Herzegovina on two occasions, and in 1840 he published his comprehensive work, *La Turquie d'Europe*. Attracted by the rich mineral resources of Bosnia and Herzegovina, the new Austro-Hungarian administration began preparations for geological exploration immediately after occupying the country in 1878. Their goal was to create a detailed geological map of the territory, based on a precise topographic foundation. This mapping was carried out in the summer of 1879 by a team of distinguished geologists from the Geological Institute (German: *k.k. Geologische Reichsanstalt*) in Vienna, including Edmund von Mojsisovics, Emil Tietze, and Alexander Bittner. Based on the data they collected with the assistance of Croatian geologist Đuro Pilar, the Geological Overview Map of Bosnia and Herzegovina (German: *Geologische Übersichtkarte von Bosnien-Hercegovina*) at a scale of 1:576,000 was created. This map was a supplement to the renowned General Geological Map of the Austro-Hungarian Monarchy by Franz Ritter von Hauer, published in 1880. The map was created using 20 colors to represent the geological formations of Bosnia and Herzegovina. To outline the boundaries and distribution of each formation, simple sketching with a compass was employed, carefully following the topographic base of the General map of Bosnia, Herzegovina, Serbia and Montenegro at a scale of 1:300,000 published in 1876. In 1887, the map *Geologische Erzlagerstätten — Karte von Bosnien* was created at a scale of 1:300,000 by the Austrian geologist Bruno Walter. Heinrich Foullon von Norbeeck published a map of the Gornji Vakuf area at a scale of 1:75,000, which is regarded as the first detailed geological survey of a region in Bosnia and Herzegovina. A new era in the study of Bosnia and Herzegovina's geology began with the arrival of Friedrich Katzer in Sarajevo. He published the first exceptionally high-quality geological maps at a scale of 1:75,000 (covering Doboj, Zenica, Jajce and Jezero, Prozor, Mostar, and Bugojno), as well as one map at a scale of 1:200,000 (Donja Tuzla), in his Geological Guide to Bosnia and Herzegovina, published in 1903 [5, 6, 7]. His most important cartographic achievement was *the Geological Overview Map of Bosnia and Herzegovina* (GOMB&H), created at a scale of 1:200,000. This significant piece of Bosnian-Herzegovinian geological cartography remains insufficiently studied, much like other maps produced during the Austro-Hungarian rule in Bosnia and Herzegovina [8-10]. Brief overviews of the production and main features of the GOMB&H were provided by [6] and [7]. A bibliographic description of a single map sheet, following the International Standard Bibliographic Description of Cartographic Materials (ISBD-CM), was provided by [11].

To effectively analyze and utilize geospatial data from historical cartographic documents, it is essential to georectify them. The goal of georectification is to establish a relationship between the coordinate system of the digital image (scanned map) and the modern reference system through georeferencing, while correcting image deformations using geometric transformation. Recent studies [12-14] have applied various georectification methods to historical maps based on 19th-century Habsburg military surveys. These topographic cartographic materials were used as the base maps for the geological maps, ensuring that the projections of the geological maps were essentially the same as those of the topographic maps [15].

The purpose of this paper is to identify an efficient method for georectifying the *Geological Overview Map of Bosnia and Herzegovina* at a scale of 1:200,000, ensuring reliable results. To achieve this, a detailed analysis of the map's mathematical and geodetic foundation is essential. The application of an appropriate geometric correction method should result in satisfactory positional accuracy for the transformed map data. This will enable the efficient integration of various existing data into a unified geospatial database.

2 MATERIAL AND METHODS

2.1 Geological Overview Map of Bosnia and Herzegovina at a scale of 1: 200,000

The Geological Overview Map of Bosnia and Herzegovina (German: *Geologische Übersichtskarte von Bosnien-Hercegovina*), at a scale of 1:200,000, was created under the initiative of Austrian geologist Friedrich Katzer, who is regarded as the founder of the geology in Bosnia and Herzegovina [16].

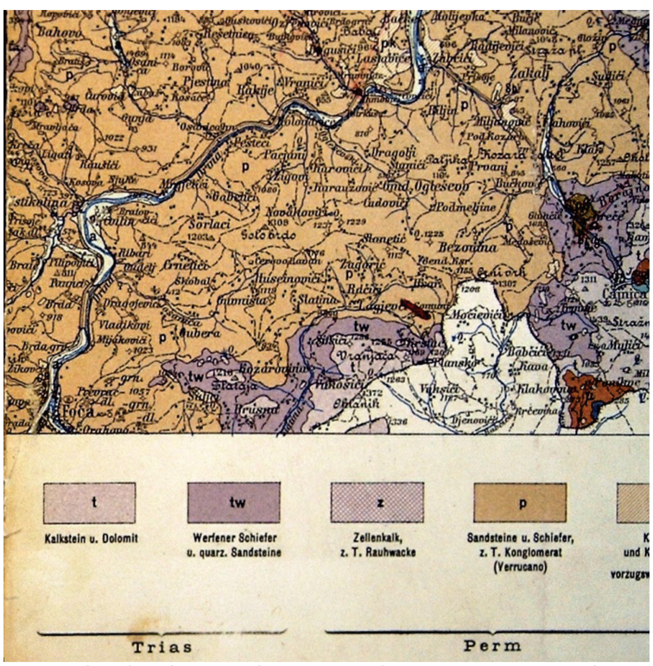


Figure 1 Clip of the Geological Overview Map of Bosnia and Herzegovina, Sheet I - Sarajevo (map is kept in Bosniak Institute Sarajevo, under the title statement "Geologische Ubersichtskarte von Bosnien - Hercegovina. 1. Sechstelblatt : Sarajevo. - Masstab 1:1.200.000", Maps B&H B, ID: 89082634).

The first sheet of this map (Sarajevo) was published in 1907 by the Geological Sector of the State Mining Directorate in Sarajevo (Fig. 1). The second and third sheets (Tuzla and Banjaluka) were published in 1910 and 1921, respectively. The fourth and fifth sheets - Travnik and Ljubuški were completed after Katzer's death by T. Jakšić and M. Milojković and published in 1929. Finally, the sixth sheet (Mostar) was produced by a group of geologists in 1953. Thus, Bosnia and Herzegovina became the first republic of the former Yugoslavia to have a comprehensive geological map covering its entire territory. The creation of this map, with interruptions, took 55 years, from Katzer's arrival in Sarajevo in 1898 until the publication of the last sheet. For many years, it served as the primary reference for a wide range of regional projects, including those in construction, mining, land reclamation, petroleum geology, hydrogeology, engineering geology, and more [7].

2.2 Georectification of Scanned Maps

The research conducted in this study involved the georectification of the fifth sheet of GOMB&H (Ljubuški), produced by Geological Institute Sarajevo in 1929 (Fig. 2), which is kept in the Archive of the Faculty of Civil Engineering, University of Sarajevo. To accomplish this, the map sheet was converted into a digital raster format using a large-format rotary scanner, resulting in a TIFF (Tagged Image File Format) image file.

Figure 2 Clip of the scanned Geological Overview Map of Bosnia and Herzegovina, Sheet V – Ljubuški (source: Faculty of Civil Engineering, Department of Geodesy and Geoinformatics, University of Sarajevo)

The scanned map contains both the errors present in the original paper map and additional scanning errors. Therefore, it is necessary to geometrically correct the map image and align it with the real world, i.e., to georeference the raster dataset. When selecting an appropriate georectification procedure for a scanned map, it is important to consider how the original analogue map was created and the types of errors that may have occurred during that process. Distortions in analogue maps can result from errors in the primary geodetic survey data, mapping inaccuracies, and deformations of the map's supporting material (such as the paper) due to factors like temperature, humidity, aging, and folding [17]. To correct the raster map deformation, it is necessary to reposition the pixels from their original locations to the corresponding ground coordinates. This requires using an appropriate mathematical model to eliminate distortions and applying a coordinate transformation. The transformation parameters are determined based on tie points (common or control points), and in the next step, all map points are transformed accordingly [3]. The investigation of the georectification of GOMB&H involved the use of various global transformation functions, including similarity, affine, projective, and polynomial transformations. Additionally, a locally sensitive transformation based on the Thin-Plate Spline (TPS) radial basis function was also explored. Detailed descriptions of these transformation methods can be found in the literature on geometric correction of raster digital images, e.g. [18].

2.3 Definition of Tie Points

The raster coordinate system of the scanned map and the map target coordinate system are connected with the tie points. Geometric deformations of the scanned map are determined and eliminated on the basis of these points. Tie points are usually defined by the intersections of the grid formed by lines of latitude and longitude (graticule). Grid intersections are the best control points as these are easily seen on the map, and their coordinates are usually precisely known [19].

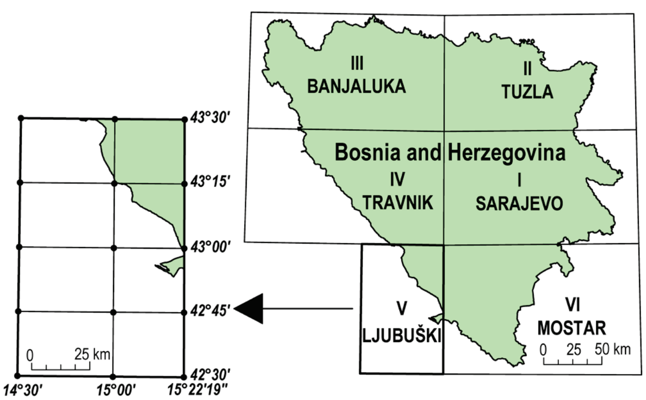


Figure 3 Map graticule of the GOMB&H Sheet V (left) and the index sheet of the 1:200,000 scale Geological Overview Map of Bosnia and Herzegovina (right)

The fifth sheet of GOMB&H contains a graticule which shows parallels every 15'. Meridians are spaced at the varying intervals. In total, 15 points representing the graticule intersections (tick marks) are available on this map sheet (Fig. 3). Since the graticule represents the mathematical framework upon which the whole map's content is based [20], it follows that graticule intersections should be clearly defined with respect to the coordinate system assigned to the geological map, as well as to the system in which the map needs to be converted. Geodetic and mathematical basis of the GOMB&H are identical to the geodetic and mathematical basis of the 1:200,000 scale General map of Central Europe (germ. *Generalkarte von Mitteleuropa*), produced by the Austro-Hungarian Military Geographic Institute (MGI). This map was created using the polyhedric projection [21].

2.4 Evaluating the Geometric Accuracy of Map Transformations

The quality of spatial information in the geometrically corrected raster image of GOMB&H is directly linked to the georectification method applied. Therefore, it is essential to evaluate the 2D (horizontal or planimetric) component of positional accuracy for all map transformation variants [22]. Absolute or external positional accuracy is defined as the accuracy of the position of features within a spatial reference system. Through this accuracy assessment, it becomes possible to determine the extent to which geometric distortions—such as those caused by differential paper shrinkage, map defects like tears, folds, and creases, or non-material-related issues—have been corrected [23].

Figure 4 Trigonometrical point at Gradina Hill, 8 km north of Ljubuški – plotted on the GOMB&H (left) and on a more recent topographic map at a scale of 1:25,000 (sheet 574-1-3, Buhovo) (right) (source: Faculty of Civil Engineering, Department of Geodesy and Geoinformatics, University of Sarajevo)

This paper uses a direct 2D accuracy evaluation method, as outlined in ISO 19157 (Geographic Information – Data Quality). The process involves comparing the dataset being assessed with an appropriate set of true or reference values (the reference dataset). To carry out this comparison, check points were defined within the GOMB&H dataset, where the coordinates in the target coordinate system are known to a higher degree of accuracy than those in the dataset being evaluated. This approach allows for the determination of the closeness between the coordinate values obtained from the georectified map and those accepted as the true corresponding positions [24]. In this context, triangulation stations (used as the basis for topographic surveying) can be employed. These stations are depicted on the map with a small triangle symbol. For the purpose of evaluating the accuracy of the transformation, 29 trigonometrical points have been selected, located within the territory of Bosnia and Herzegovina and the neighboring region of Dalmatia. These triangulation stations are positioned on summits to ensure visibility and prominence, with their locations coinciding with points of a more modern trigonometric network (Fig. 4). Specifically, the marks of these triangulation stations were later used in a geodetic survey aimed at establishing the trigonometric network of the former Yugoslavia. As a result, these points became part of a new triangulation network that served as the foundation for the state survey. Consequently, the coordinates of these points are known with significantly greater accuracy than those that could be obtained through map-based measurements. Therefore, the required accuracy criterion for the reference data was met, allowing the triangulation stations to be used as check points.

Since the ISO 19157 defines only general principles and procedures, the US National Standard for Spatial Data Accuracy (NSSDA) was applied in this research. The NSSDA uses root-mean-square error (*RMSE*) to estimate positional accuracy at 68.3 % confidence level [25]. The *RMSE* is calculated with the use of remained positional distortions d_{EN}:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n} d_{ENi}^2}, \quad (1)$$

where: $d_{EN} = \sqrt{d_E^2 + d_N^2}$, $d_E = E^{\text{ref}} - E^{\text{tr}}$, $d_N = N^{\text{ref}} - N^{\text{tr}}$ - differences between reference and transformed coordinates along *E* and *N* axis.

3 RESULTS AND DISCUSSION

As mentioned earlier, the GOMB&H sheet contains 15 points representing the intersections of the graticule. Using these tie points, various transformation models were applied, where the Stereographic projection and the Hermannskogel datum were used. Before applying the transformation, longitudes were corrected because the GOMB&H was created using the 'Parisian' mapping system, which is based on the Prime Meridian of Paris, with an offset from Greenwich of $\Delta\lambda = 2°20'13.98''$E.

Since the application of different transformation functions results in varying positions for each pixel in a corrected raster image, it is essential to assess the planimetric accuracy of the geometric transformations used to georeference the scanned map. To accomplish this, 29 predefined check points, based on triangulation stations, were used to evaluate the actual effects of different transformation models. Table 1 presents the key accuracy indicators for the transformed check points, including distortion residuals along the *E* and *N* axes, as well as the *RMSE*.

The worst results were obtained using the similarity (Helmert) transformation. The accuracy of this method is 1.26 mm at the map scale (on the map sheet), which corresponds to 253 m at full scale (on the ground). More than one-third of the check points exhibit significant positional distortions of 250 m or more, with a maximum error of 444 m (or 2.22 mm on the map). The analysis revealed that the other transformation methods outperformed Helmert's method, achieving roughly twice the accuracy of the similarity transformation. However, it is clear that all of these methods had limitations in eliminating systematic distortions from the geological map. None of the transformations used were able to remove significant systematic errors from the georeferenced map. This conclusion is reinforced by the normal distribution curve of the remaining distortions along the *N*-axis following the TPS transformation (Fig. 5), which was generated using the 'fitmethis' MATLAB function [26]. The noticeable shift in the distribution curve, indicative of the remaining systematic errors, is readily observable. The achieved accuracy of 0.65 mm on the map using the affine transformation, and 0.75 mm with the TPS and second-order polynomial transformations, is notably lower than the accuracy reported in [27]. In that study, the accuracy of the Habsburg Special Map (scale 1:75,000; SM75) was evaluated. After correcting for distortions caused by paper drying and shrinkage, the planimetric accuracy of the SM75 at the map scale was 0.4 mm, which corresponds to the plotting accuracy on paper. It is important to note that each sheet of the 1:200,000-scale General Map of Central Europe was created by combining eight 1:75,000 sheets into a single mosaic [13].

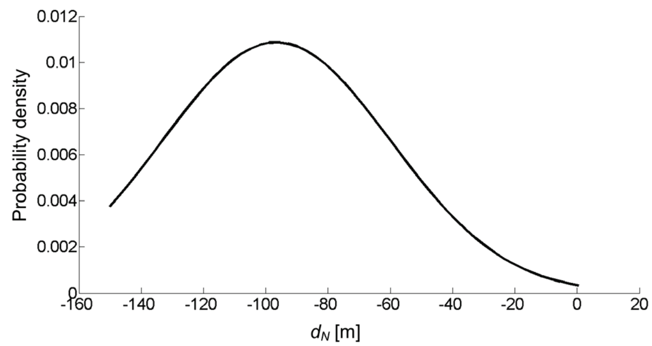


Figure 5 Distribution curve of remaining distortions d_N after applying the TPS transformation

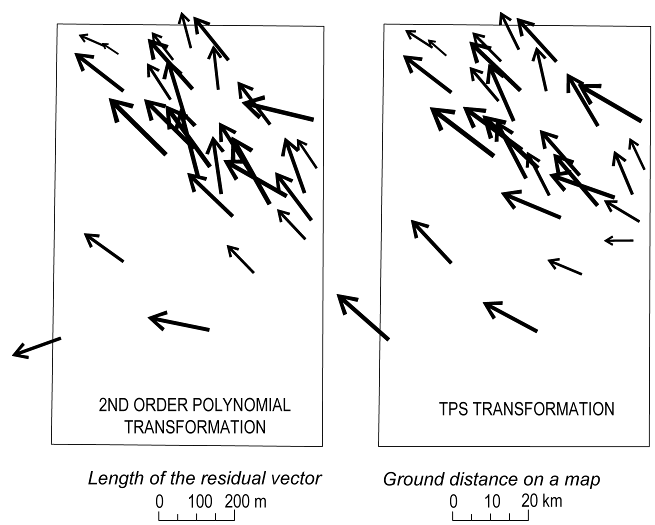


Figure 6 Remaining distortions of check points after applying 2nd order polynomial transformation (left) and TPS transformation (right)

It is therefore clear that the remaining distortions in the GOMB&H are not caused by uncorrected scanning errors or map sheet shrinkage. This is supported by the graphical representation of the positional errors at the check points. To illustrate the local geometric characteristics of the transformed map, planimetric accuracy was visualized using residual vectors (Fig. 6). Each residual vector represents the difference between the reference coordinates and the transformed coordinates of the triangulation station. Fig. 6 clearly demonstrates that, after the geometric transformation, certain positional distortions remain at the check points, indicating the overall homogeneity of the transformed data.

It also shows that the majority of deviations following the TPS and second-order polynomial transformations exhibit consistent propagation, with a noticeable uniform pattern in the vector orientation. These residual vectors reveal significant systematic errors that persist in the transformed map, i.e. the content of the GOMB&H is shifted approximately 150 meters to the northwest relative to the graticule tick marks.

3.1 Method for Enhancing the Georectification of GOMB&H

Since it was shown that transformations based on the GOMB&H graticule defined directly in the MGI 1901 system yield unsatisfactory planimetric accuracy, an alternative approach to improve the georectification quality was investigated. It is important to note that the topographic content of the GOMB&H was created using data collected during the Third Military Mapping Survey of Austria-Hungary. This survey relied on a network of trigonometric points, with coordinates referenced to the Vienna University Datum and the Bessel 1841 ellipsoid.

On the other hand, the current coordinate system (MGI 1901) used in Bosnia and Herzegovina is based on the Bessel ellipsoid and the Hermannskogel Datum. It is essential to point out that the coordinates of triangulation stations in the Vienna University System were computed using preliminary adjusted regional networks with different starting points, while the Yugoslav triangulation represents a homogeneous, final adjusted network oriented to the Hermannskogel [28]. Therefore, nonuniform disparities in point coordinates arise from differences between the geodetic basis of the GOMB&H and the more modern Yugoslav triangulation. The disparities at identical stations are significantly larger than what would be expected as normal errors in coordinate determination. For this research, a method was developed to compute the graticule intersections of GOMB&H with respect to the Bosnian-Herzegovinian state coordinate system (Fig. 7). The procedure is based on the coordinate differences between the Vienna University system and MGI 1901 [29]. The coordinate corrections at an arbitrary point are determined by linear interpolation between neighboring isolines of the differences in latitude and longitude, $\Delta\varphi$ and $\Delta\lambda$. This approach defines a set of 15 tie points (map grid intersections) with corrected coordinates in the target coordinate system, which were then used for the map's georectification.

Tab. 2 presents the main 2D accuracy indicators for the transformed check points, which correspond to the 29 previously defined triangulation stations. The analysis of the values presented in Tab. 2 highlights the limitations of the 4-parameter similarity, 6-parameter affine, and 8-parameter projective transformations in eliminating geometric distortions from the geological map. Statistical indicators reveal that most positional errors could not be corrected by these transformation functions, demonstrating the persistence of significant distortions after applying the similarity, affine, and projective transformations. Moreover, there is no significant improvement in the correction of local systematic errors compared to the values in Tab. 1. This is further confirmed by the residual vectors resulting from these transformations (Fig. 9 and Fig. 10). The vectors are grouped and generally point in the same direction, indicating systematic influences or errors. The vectors exhibit high magnitudes (up to 333 m), and it is clear that the variations in their values are quite pronounced.

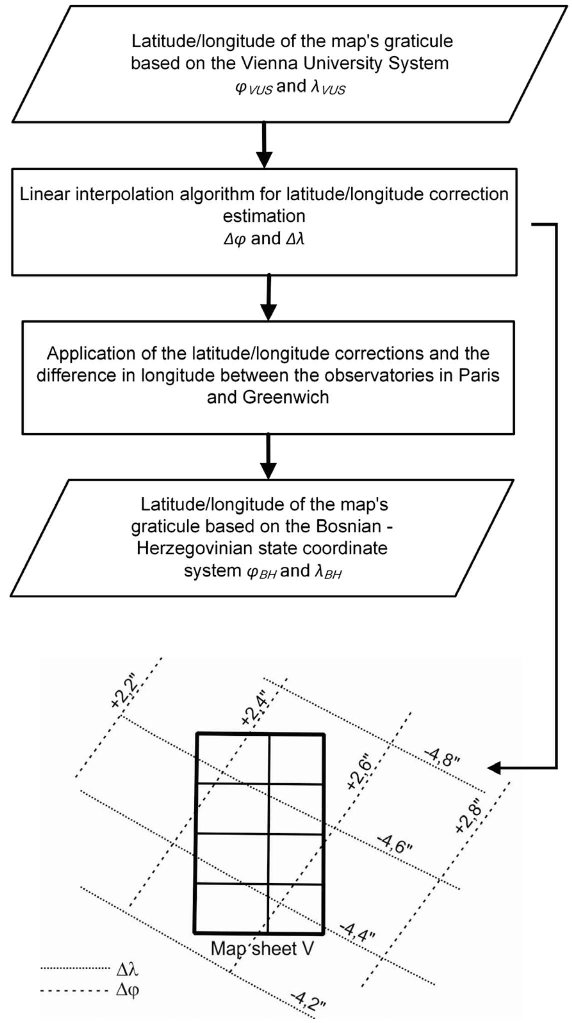


Figure 7 Flowchart for determining the corrected GOMB&H graticule coordinates

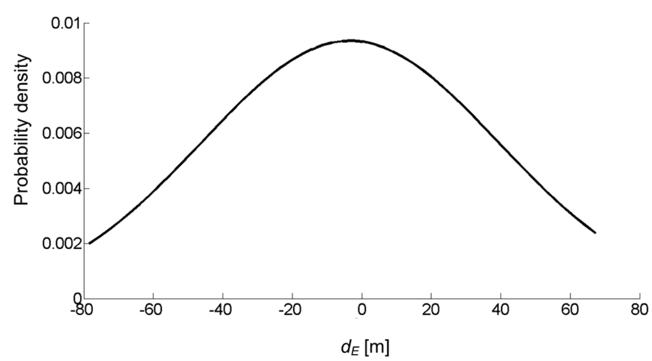


Figure 8 Distribution curve of remaining distortions d_E after performing the TPS transformation

The geometric correction of the GOMB&H using a 2nd order polynomial transformation increases the number of transformation parameters to 12, which positively impacts the elimination of systematic distortions. This transformation significantly reduces deformations at the check points, resulting in more homogeneous outcomes. This suggests that the uniform layout and spacing of the graticule lines in the geological map help effectively eliminate most of the systematic errors after applying the polynomial transformation. Importantly, no large, undesired positional distortions remain, with the *RMSE* in this case around 70 m, or 0.35 mm at the map scale.

Table 1 Summary of residual statistics for 29 transformed checkpoints across different transformation methods

Indicator		Similarity			Affine			Projective			Polynomial 2nd order			TPS		
		d_E	d_N	d_{EN}	d_E	d_N	d_{EN}	d_E	d_N	d_{EN}	d_E	d_N	d_{EN}	d_E	d_N	d_{EN}
Minimum [m]		–114	–406	103	–71	–244	15	–112	–201	23	13	–179	50	26	–150	62
Average [m]		79	–144	236	38	–76	111	12	–97	128	89	–101	145	100	–97	144
Maximum [m]		420	115	444	202	61	263	250	71	251	188	46	211	171	0	211
Range [m]		535	521	341	273	306	248	362	272	227	175	224	160	145	151	148
RMSE [m]		150	203	253	66	108	127	75	118	140	100	113	151	108	103	150
Remaining distortion distribution %	0-50 m	31.0	17.2	0.0	62.1	37.9	24.1	59	28	7	20.7	17.2	0.0	17.2	13.8	0.0
	50-100 m	27.6	13.8	0.0	27.6	27.6	17.2	28	17	28	41.4	31.0	17.2	34.5	34.5	17.2
	100-150 m	10.3	17.2	17.2	6.9	13.8	34.5	7	31	31	27.6	34.5	27.6	31.0	48.3	24.1
	150-200 m	10.3	13.8	24.1	0.0	13.8	13.8	3	21	28	10.3	17.2	48.3	17.2	3.4	51.7
	200-250 m	10.3	17.2	20.7	3.4	6.9	6.9	3	3	3	0.0	0.0	6.9	0.0	0.0	6.9
	> 250 m	10.3	20.7	37.9	0.0	0.0	3.4	0	0	3	0.0	0.0	0.0	0.0	0.0	0.0

Table 2 Summary of residual statistics for 29 transformed checkpoints across different transformation methods (improved solution)

Indicator		Similarity			Affine			Projective			Polynomial 2nd order			TPS		
		d_E	d_N	d_{EN}	d_E	d_N	d_{EN}	d_E	d_N	d_{EN}	d_E	d_N	d_{EN}	d_E	d_N	d_{EN}
Minimum [m]		–215	–325	34	–174	–163	30	–215	–120	43	–91	–99	8	–78	–71	28
Average [m]		–23	–64	188	–65	4	107	–91	–16	129	–14	–21	66	–3	–16	56
Maximum [m]		317	195	333	97	141	174	145	154	221	83	129	133	67	80	86
Range [m]		532	520	299	271	304	144	360	274	178	174	228	125	146	151	58
RMSE [m]		130	157	204	84	76	114	118	69	136	47	54	72	43	40	58
Remaining distortion distribution %	0-25 m	17.2	3.4	0.0	10.3	24.1	0.0	3.4	13.8	0.0	34.5	31.0	3.4	31.0	34.5	0.0
	25-50 m	6.9	13.8	3.4	20.7	24.1	6.9	13.8	34.5	3.4	27.6	31.0	31.0	34.5	44.8	37.9
	50-75 m	13.8	10.3	6.9	17.2	10.3	13.8	3.4	24.1	6.9	24.1	20.7	20.7	31.0	17.2	44.8
	75-100 m	10.3	10.3	0.0	34.5	24.1	27.6	24.1	13.8	13.8	13.8	13.8	34.5	3.4	3.4	17.2
	100-125 m	13.8	10.3	10.3	10.3	6.9	20.7	20.7	10.3	27.6	0.0	0.0	6.9	0.0	0.0	0.0
	> 125 m	37.9	51.7	79.3	6.9	10.3	31.0	34.5	3.4	48.3	0.0	3.4	3.4	0.0	0.0	0.0

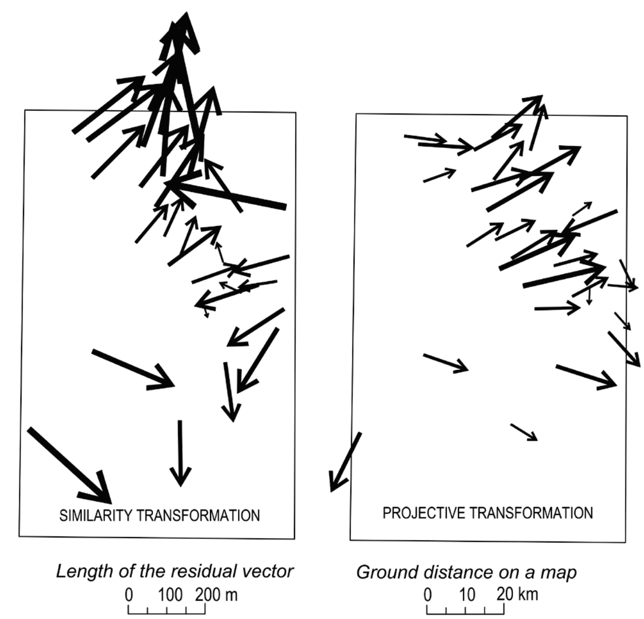


Figure 9 Remaining distortions of check points after applying similarity transformation (left) and projective transformation (right)

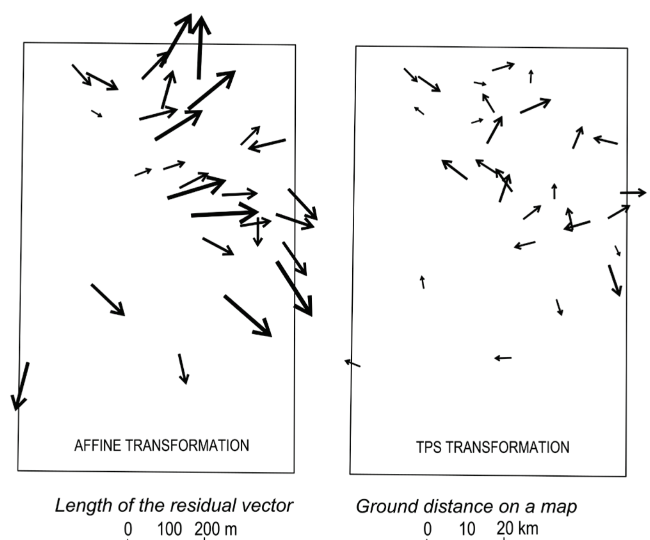
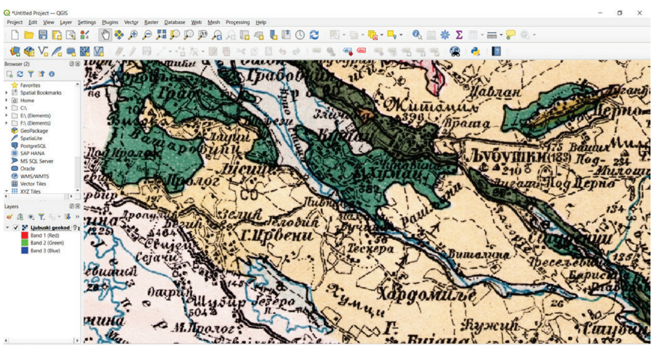
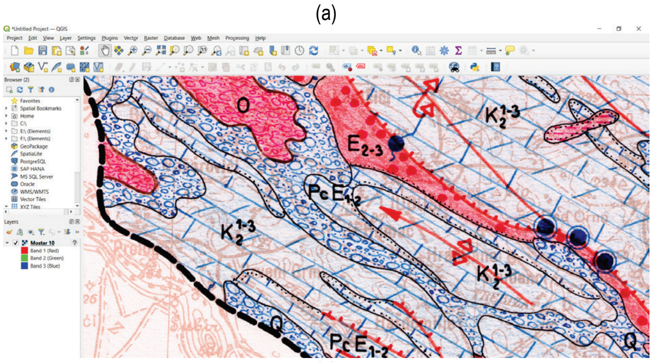


Figure 10 Remaining distortions of check points after applying affine transformation (left) and TPS transformation (right)

The best results in terms of transformation quality were achieved using the TPS transformation (defined by 64 parameters), with an *RMSE* of 0.29 mm at the map scale. The distribution curve shows that the differences between the theoretical and transformed coordinates of the check points have an arithmetic mean close to zero (Fig. 8). After eliminating significant systematic errors using the TPS transformation, 100 % of the check points showed a d_{EN} of less than 0.5 mm at the map scale. In comparison, the second-order polynomial transformation achieved this for 86 % of the check points, affine transformation for 48 %, projective transformation for 24 %, and similarity transformation for only 10 %. The maximum positional deviation resulting from the TPS transformation was reduced by a factor of four compared to the value obtained using the similarity transformation. This suggests that the uniform arrangement and spacing of the graticule lines in the GOMB&H enable locally sensitive transformations to effectively eliminate systematic errors from the map. The residual vectors on the map georectified using the TPS method were significantly reduced (Fig. 10) compared to those in Fig. 6. Fig. 9 shows that the changes in the vectors' orientation and intensity are moderate, confirming that choosing an appropriate transformation model can effectively eliminate a large portion of the systematic distortions caused by map drafting errors, aging, scanning, and other factors



(a)



(b)

Figure 11 Two georeferenced geological maps of the Ljubuški area displayed within the QGIS environment: (a) GOMB&H; (b) Geological map of Bosnia and Herzegovina at a 1:200,000 scale, produced by the Geological Institute in Belgrade, 1967 (source: University of Sarajevo - Faculty of Civil Engineering, Department of Geodesy and Geoinformatics)

The TPS transformation of the scanned raster map produced a geometrically corrected map, now aligned with the official Bosnian-Herzegovinian state coordinate system. The accuracy of well-defined points of detail plotted on the map is expected to be within ±0.5 mm. This enables the creation of a cartographic database that allows data from the GOMB&H to be compared, overlaid, and integrated with geological data from its more modern counterparts (Fig. 11). Of particular interest is the comparison of maps created at different times that depict the same geographic area.

4 CONCLUSION

This research emphasizes the critical importance of selecting the correct transformation base (control points) and the appropriate functional transformation model in effectively eliminating systematic errors caused by factors such as paper deformation, scanning irregularities, drafting and reproduction errors, and misaligned coordinate systems. The study confirmed that the quality of map georeferencing depends largely on the precise definition of control points in both the original map's coordinate system and the target coordinate system. Nonuniform discrepancies in point coordinates, resulting from differences between the geodetic basis of the Geological Overview Map of Bosnia and Herzegovina (GOMB&H) and the more modern triangulation, were successfully identified. It was demonstrated that transformations based on the GOMB&H graticule, which is directly defined within the MGI 1901 system, resulted in unsatisfactory planimetric accuracy, with the *RMSE* reaching 0.65 mm at the map scale. This was because the topographic content of the map, including the triangulation stations, was referenced to the Vienna University Datum rather than the Hermannskogel datum. The resulting discrepancies at the same stations were irregular and considerably larger (up to 1.3 mm on the map) than expected normal errors in map measurement. As a result, the coordinates of the intersections of the meridians and parallels on the map were adjusted to align with the Bosnian-Herzegovinian state coordinate system. This correction yielded satisfactory transformation results, with an *RMSE* of 0.29 mm at the map scale. This level of accuracy can be achieved if all available graticule intersections are incorporated into the transformation model.

The study also demonstrated that selecting the appropriate functional model in the transformation process is crucial for achieving reliable georectification results. Statistical and graphical indicators clearly show how suitable transformation functions can reduce geometric distortions in the map content. Systematic errors in the scanned map cannot be effectively corrected by global transformations relying on a small number of parameters. The assessment of geometric accuracy revealed poor results when georectification was performed using common procedures, such as similarity, projective, or affine transformations. In contrast, more complex polynomial transformations, and especially the locally sensitive TPS transformation—proved successful in reducing significant geometric distortions in the geological map.

By using the correct approach for the geometric processing of the GOMB&H sheet—printed 95 years ago on standard cartographic paper and preserved under poor conditions—it was determined that the remaining distortions in the transformed points were random. This resulted in satisfactory positional accuracy for the georeferenced map, with a representative sample of triangulation stations plotted in their true positions at map scale to an accuracy better than ±0.5 mm.

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