50
Review paper I Прегледни научни рад
DOI 10.7251/STP2215521R
ISSN 2566-4484

Stevan Radojčić, Visoka građevinsko geodetska škola Beograd, stradojcic@sezampro.rs

ASSESSMENT OF THE POSITIONAL ACCURACY OF THE TOPOGRAPHIC MAP 1:50.000 MADE BY MGI

Abstract

The paper describes the methodology of testing and evaluating the positional accuracy of the topographic map of Serbia in the scale of 1: 50 000, published by the Military Geographical Institute from Belgrade, and gives an overview of the obtained results.The assessment of accuracy is done by comparing the planimetric coordinates of the map points to the coordinates of the same points as determined by a field measurements of very higher accuracy, according to American National Standard for Spatial Data Accuracy.

Keywords: Positional accuracy, Topographic map 1:50. 000, MGI, NSSDA

ОЦЕНА ПОЛОЖАЈНЕ ТАЧНОСТИ ТОПОГРАФСКЕ КАРТЕ 1:50.000 У ИЗДАЊУ ВГИ

Сажетак

У раду је описана методологија испитивања и оцењивања положајне тачности топографске карте Србије у размери 1:50 000 у издању Војногеографског инситута из Београда, и дат је преглед добијених резултата. Оцена тачности је извршена на основу поређења планиметријских координата тачака мерених на карти са координатама истих тачака одређеним теренским мерењима пуно веће тачности, према Америчком националном стандард за тачност просторних података.

Кључне ријечи:Положајна тачност, Топографска карта 1:50.000, ВГИ, NSSDA

1. INTRODUCTION

Quality of the cartographic products and spatial databases is of great importance for both, manufacturers and users. With the growing importance of data on space for everyday life, the importance of defining the concept of quality of data on space, its content, as well as the way of testing and presenting results has grown.

The positional (geometric) accuracy of the map is, according to the ISO19113 standard, one of several elements of the map quality that can be quantified (Table 1) [1]. Positional accuracy determines how closely the position of discrete objects shown on a map or in a spatial database agree with the true position on the ground.

Table 1.Elements and sub/elements to categorize data quality aspects in ISO 19113

ELEMENTS AND SUB-ELEMENTS	DESCRIPTION
Completeness commission omission	Presence or absence of features, their attributes and relationships
Logical consistency conteptual consistency domain consistency format consistency	Degree of adherence to logical rules relating to data structure, attributes and their relationships
Positional accuracy absolute or external relative or internal grided data	Closeness of positions (reported coordinate values, relative positions of features or gridded data positions values) to a reference (“true”) values
Temporal accuracy accuracy of a time measurement temporal consistency temporal validity	Temporal accuracy of attributes and their mutual relationships
Thematic accuracy classification correctness non-quantitative attribute correctness quantitative attribute correctness	Accuracy of quantitative attributes and correctness of non-quantitative attributes, as well as attribute classifications and their relationships

Positional accuracy has traditionally been evaluated using control points. Following this idea, there are many statistical Positional Accuracy Assessment Methodologies (PAAM), for example: National Map Accuracy Standard (NMAS), Engineering Map Accuracy Standard (EMAS), National Standard for Spatial Data Accuracy (NSSDA), NATO STANAG 2215, ASPRS Accuracy Standards for Large-Scale Maps (ASLSM), ASPRS Positional Accuracy Standards for Digital Geospatial Data (ASDGD), etc.

Different maps have different positional accuracy because of different influences of random and sistematic errors originated from methodology of map production. Moreover, even the different sheets within the same multi-sheets map could have different positional accuracy

A variety of factors affect the positional accuracy of digital spatial data. Error can be introduced by: the specifications of the techniques used for the survey and further processing, ground control reliability, source material, digitizing methods, generalization, symbol interpretation…and printing limitations. Individual errors derived from any one of these sources is often small, but collectively, they can significantly affect data accuracy. The PAAM give an overall assessment, and if it is not in line with expectations, the causes must be analyzed separately, by other methods and procedures.

It is known that positional accuracy is of great importance for the usefulness of maps, specially if it refers to large scale maps, such as digital topographic map at scale of 1:50000. It is a basic map of wide application used in navigation, planning and monitoring. This map is the most frequently used map in the Serbian Armed Forces (like in others armies, too), which is the main reason for checking its quality.

2. STANDARD NSSDA

For evaluation, the procedure provided by the American National Standard for Spatial Data Accuracy (NSSDA) from 1998 [2] was used, with certain modifications. The standard is developed by Federal Geographic Data Committee, so not by a standardization organization, but it turned out to be suitable for this occasion. The NSSDA provides a method for assessing accuracy of geographical data in both printed and digital (raster and vector) form, for horizontal as well as vertical accuracy. For positional accuracy evaluation, it uses the traditionall approach: comparing two sets of data – one with values taken (measured) from a cartographic product and another with values of the same quantities (ie. same points)with reference („true“) value.

Reference values must be at least three times more accurate than the first one, and must be acquired separately from the data set being tested. This more accurate source material could be, for example, surveyed data or values taken from a much larger scale product, with scale ratio of 1:3 or more. In the case described in this paper, the coordinates of the control points were determined by field measurements, with an accuracy that is more than 20 times higher than the expected accuracy of the map.

For the purpose of accuracy testing only well-defined points are used. By standard, well-defined points are those that are easily visible or recoverable on the ground , on the independent source of higher accuracy, and on the product itself. In the case of maps, suitable well-defined points are represent right-angle intersections of roads, railroads or other linear mapped features, monuments, lonely items, etc.

Since the positional accuracy of one map sheet is assumed to be uniform, the well-defined points must be evenly distributed across the map sheet. Within a sheet, points may be distributed so that are spaced at intervals of at least 10% of the diagonal distance across sheet *and* at least 20% of the points are located in each quadrant of the map sheet (Figure 1.)

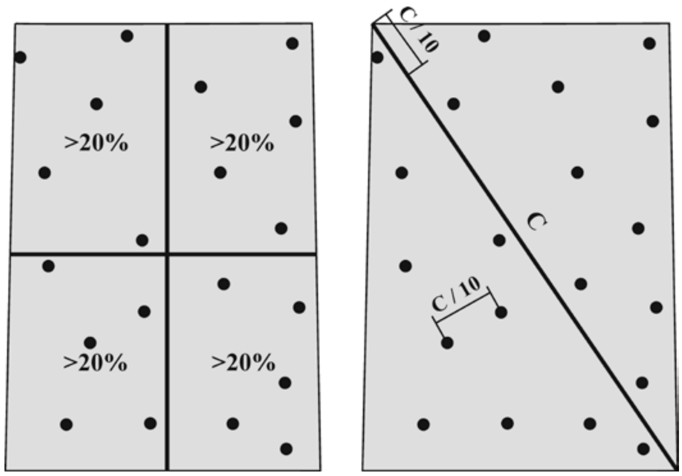

Figure 1. *Recommended distribution and distance of test points*

The standard requires a minimum of 20 test points shall be tested, distributed to reflect the geographic area of interest.

Unlike the NSSDA which does not take care what geographical element that point belongs to, in this assessment the points for assessment horizontal positional accuracy are chosen to belong to the three basic geographic elements, printed in three different colours – black (roads, houses, railway, etc.), blue (hydrography) and green (vegetation) or combination of them (cross points of diferent geographic elements, for example cross-point of road and railway and so on). In accordance with this, a matrix of well-defined points was formed for each map sheet (Figure 2). That matrix was used in planning and governing the estimation process (S – black, H – blue. V - green).

Also, the minimum number of test points per sheet has been increased to 25.

	S	**H**	**V**
S	12	7	2
H		4	1
V	**Σ=27**		1

Figure 2. *Matrix of well-defined points on one sheet*

2.1. CALCULATING POSITIONAL ACCURACY ESTIMATION

For *horizontal accuracy estimation*, for each data set the root mean square errorby axes($RMSE_y$ and $RMSE_x$) are calculated, according to:

$$RMSE_y = \sqrt{\frac{1}{n}\sum_{1}^{n} {d_y}_i^2} \ ; \ RMSE_x = \sqrt{\frac{1}{n}\sum_{1}^{n} {d_x}_i^2} \tag{1}$$

where:

$dy_i = (y_{map} - y_{ref})_i$ – differences of the measured and reference values along the y - axis

$dx_i = (x_{map} - x_{ref})_i$– differences of the measured and reference values along the x - axis

n– the number of test points

i– an integer ranging from 1 to *n*

Horizontal error at point *i* is defined as:

$$RMSE_i = \sqrt{{d_y}_i^2 + {d_x}_i^2} \tag{2}$$

and RMSE of the data set (sheet) is:

$$RMSE_r = \sqrt{\frac{1}{n}\sum_{1}^{n} \mathrm{dy}^2 + \frac{1}{n}\sum_{1}^{n} \mathrm{dx}^2} = \sqrt{\mathrm{RMSE}_y^2 + \mathrm{RMSE}_x^2} \tag{3}$$

In order to get accuracy reported at the 95% confidence level (denote by $Accuracy_r$), further computing depends on whether $RMSE_y$and $RMSE_x$ are equal to each other or not.
If $RMSE_y = RMSE_x$, than:

$$RMSE_r = \sqrt{2 \cdot \mathrm{RMSE}_y^2} = \sqrt{2 \cdot \mathrm{RMSE}_x^2} = 1{,}4142 \cdot RMSE_y = 1{,}4142 \cdot RMSE_x \tag{4}$$

If errors are normally distributed and independent in each the x- and y- component error, the factor 2,4477 is used to compute horizontal accuracy at the 95% confidence level [3], so:

$$Accuracy_r = 2{,}4477 \cdot RMSE_r / 1{,}4142 = 1{,}7308 \cdot RMSE_r \tag{5}$$

Analogous, if $RMSE_y \neq RMSE_x$,

$$\begin{aligned} Accuracy_r &= 2{,}4477 \cdot 0{,}5 \cdot \left(RMSE_y + RMSE_x\right) \\ &= 1{,}2238 \cdot \left(RMSE_y + RMSE_x\right) \end{aligned} \tag{6}$$

For *vertical accuracy estimation*, for each data set the root mean square error of the vertical coordinate (height) is calculated, according to:

$$RMSE_z = \sqrt{\frac{1}{n}\sum_{1}^{n} \left(z_{map} - z_{ref}\right)_i^2} \tag{7}$$

where:

z_{map} – vertical coordinate of the *i* th test point in the dataset

z_{ref} – vertical coordinate of the *i* th test point in the independent source of higher accuracy

n– the number of test points

i– an integer ranging from 1 to *n*

If vertical error is normally distributed, the factor 1,9600 is applied to compute linear error at the 95% confidence level [3].Therefore, vertical accuracy, $Accuracy_z$, shall be computed by the formula:

$$Accuracy_r = 1{,}9600 \cdot RMSE_z \quad (6)$$

Although the NSSDA does not provide procedures for blunder and sistematic error detection, the differences between the measured and reference values of each sheet were tested for them according to the testing procedures developed in NATO STANAG 2215 [4] and adjusted for this occasion [5].

3. TOPOGRAPHIC MAP 1:50.000 MADE BY MGI

The Military Geographical Institute (MGI) is the oldest Serbian geodetic and cartographic institution, fonded in 1876. From its establishment until today, MGI is the only one that performs systematic surveys and issues topographic maps for the territory of the Republic of Serbia.

The map whose accuracy was assessed on this occasion is a topographic map in the scale of 1:50.000, created in the period from 1988 to 1995 by photogrammetric survey, therefore not by generalizing a topographic map 1: 25.000.

The territory of Serbia is covered by 204 sheets with format 15′x15′(sheets are printed in 8 colors) that were scanned and georeferenced in 2003 (Figure 3.).

A laser scanner-photoploter Optronic P-5040-HR made by Intergraph was used for the scanning of the map sheets. The sheets were scanned with *.tiff format, with RGM scanning modul with resolution 254 ppi, or 0,1 mm related to the map scale (or 5 m actual size) [6]. The georeferencing was made with domestic software Mapsoft 2000 (modul Digiscan 2000), designed for georeferencing binary and color rasters, about 190 points on each sheet (crosses of gridelines) and method of collocation with filtering in calculating transformation parameters for each sheet. A georeferencing sheet error of less than 2 m (1/2 pixel) was considered good quality.

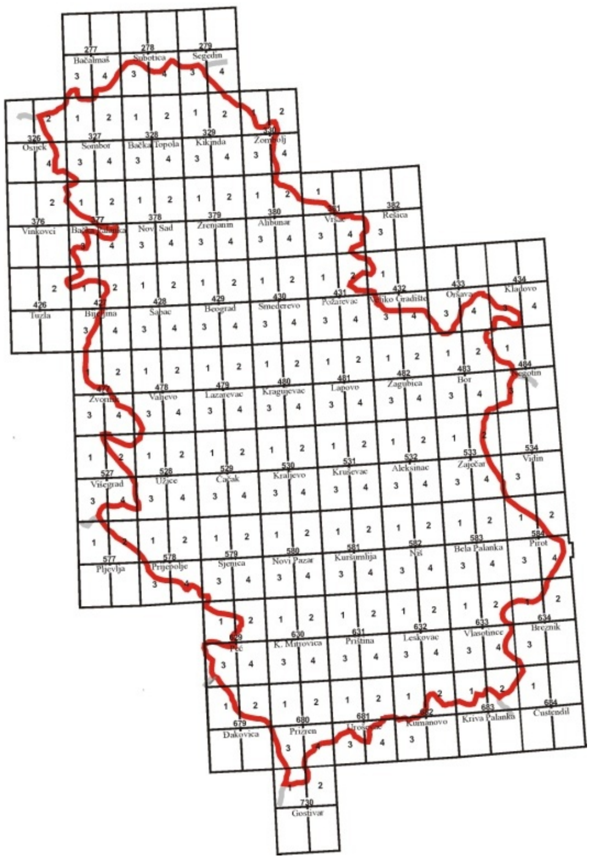

Figure 3. *Topographic map 1:50.000 review sheet*

3.1. A PRIORI ACCURACY ASSESSMENT

The apriori accuracy assessment is an integral part of the geometric accuracy assessment of the map. This is a preliminary assessment obtained by summing up the individual errors that occur in the process of making a map, according to the rules of propagation of errors. In order to determine it, it is necessary to know the process of making a mapin detail, ie to consider the sources of errors in individual phases of map making and the rules of their actions. Although the estimation of individual errors cannot be performed exactly, the previous estimation of accuracy is important both in the preparatory work for the production of the map and in the accuracy tests performed after the production of the map.

Although an a priori accuracy estimation has some deficiency, it is of help in the preliminary phase of map producing and in the a posteriori accuracy estimation phase. Preliminary accuracy assessment for topographic map 1: 50.000 was performed based on 10 errors significant for defining positional accuracy (Table 2.).

Table 2.Individual errors in the proces of map making

Notation	Error of	Value ± [mm]
σ_1	cartographic source	0,15
σ_2	Mounting of editing original	0,07
σ_3	copying the editing original	0,13
σ_4	generalizing and drawing the compiling original	0,20
σ_5	making engraving templates	0,08
σ_6	engraving	0,12
σ_7	fitting new content	0,12
σ_8	color matching	0,10
σ_9	scanning and georeferencing	0,11
σ_{10}	measurements on map	0.04

Accordingly, the total error is:

$$\sigma = \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2 + ... + \sigma_{10}^2} = 0{,}35 \text{ mm} \quad (5)$$

The values of individual errors are taken from the relevant literature and reported research (eg [7]), except the error of measuring coordinates on the map σ_{10}which was determined within this research, under the same conditions under which measurements were later performed (the same mouse, monitor, screen magnification, software, operator, etc.) [8].

In order to get accuracy reported at the 95% confidence level (denote by $Accuracy_{apr}$), given value is multiple with 1,7308 ie $Accuracy_{apr}$= 1,7308·σ = 0,60

3.2. ASSESSMENT OF HORIZONTAL ACCURACY

The assessment of horizontal accuracy was performed in two ways: (1) by differences of coordinates of *trigonometric points* measured on the map and correspondent reference coordinates taken from the Catalog of the state trigonometric network and (2) by differences of coordinates of clearly defined points measured on the map and correspondent reference coordinates measured in the field GPS method.

3.2.1. Assessment using trigonometric points

The importance of assessing the horizontal accuracy of the map based on the points of the trigonometric network is that they provide insight into the upper limit of the accuracy of the map. Therefore, no other element of the map content should have better indicators of horizontal accuracy.

All trigonometric points for 158 sheets were processed. That is 77% of total number of sheets, (Figure 4., left), ie an average of about 170 points per sheet. Twenty-one sheets covering the territory of neighboring countries were assessment on the basis of points on Serbian territory only, ie the points were not evenly distributed throughout the sheet.

In the first step, differences of measured and reference coordinates were formed for each sheet, which were analyzed in order to detect and eliminate possible gross errors. In the second step, the differences were processed according to the NSSDA. Processing was performed in Microsoft Excel, for each sheet in a separate file (Figure 5).

The average value of the *Accuracy$_r$* measure (95% confidence level) is 15,6 m (0,31 mm), and ranges from 10,7 m to 23.6 m (0.21 mm to 0.47 mm).

It should be noted that the number of measurements rejected based on the blunder detection test was less than 5% per sheet.

So, it can be concluded that the horizontal positional accuracy of topographic map 1: 50.000, estimated on this way, is consistent with the expected.

Since horizontal accuracy indicators differ from sheet to sheet, it is justified to ask the question whether the achieved accuracy is homogeneous, ie whether the differences in accuracy indicators are significant. In order to analyse the homogenity of the different map sheets, the ANOVA method was used [9] (available as a module in MS Excel). The analysis showed that the obtained results can be considered, in statistical terms, as results of the same accuracy, except for twelve sheets that had excessive errors.

3.2.2. Assessment using well-defined points

This assesment was performed for 76 sheets. That is 37% of total number of sheets (Figure 4., right), but it should be borne in mind that it was not possible to measure in the territory of Kosovo and Metohija and that a number of sheets mostly cover the territory of neighboring countries where it was also not possible to measure. In addition, field measurements were not performed systematically, but from time to time, often after the completion of some other task in that territory. However, the survey covered all categories of terrain in Serbia (plains, mountains, forests, urban and rural, etc.) and all characteristic periods of making a topographic map 1: 50,000.

The field measurements on well-defined points were carried out with a GPS Trimble *Geoexplorer 3* receiver. The receiver was regularly tested on control points. The accuracy of the GPS positioning in national map grid system, as defined by the root mean square error of a single point was 2.51 m, or half of a pixel on map sheet.

The number of well-defined points per sheet ranged from 25 to 38, selected and arranged according to NSSDA requirements. The most numerous were the points shown on the map in black color (intersections of roads, railways or other linear mapped features, monuments, lonely buildings, etc.). The points shown in blue (hydrography) were less represented, and the least represented points were green (vegetation); on many sheets not a single suitable point of vegetation could be found.

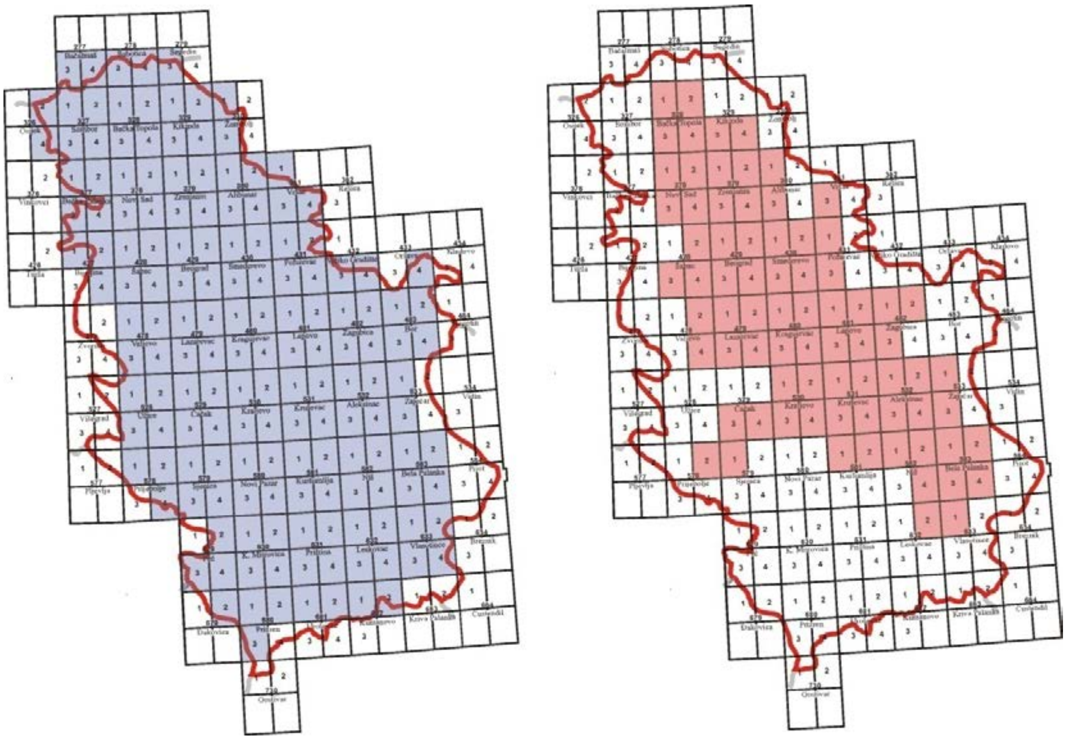

Figure 4. *Assessment using trigonometric points (left) and assessment using well-defined points (right)*

The coordinates obtained by GPS measurements were compared with the map coordinates of the common points in the same way as it was done for trigonometric points.

The average value of the $Accuracy_r$ measure (95% confidence level) is 23,9 m (0,48 mm), and ranges from 19,7 m to 35.6 m (0.39 mm to 0.71 mm).

It should be noted that the number of measurements rejected based on the blunder detection test was also less than 5% per sheet.

After the analysis of homogenity, it was found that nine sheets were statistically different and they were rescaned and rechecked. But, that did not change the situation. Further analyzes did not give a definite conclusion about the possible causes.

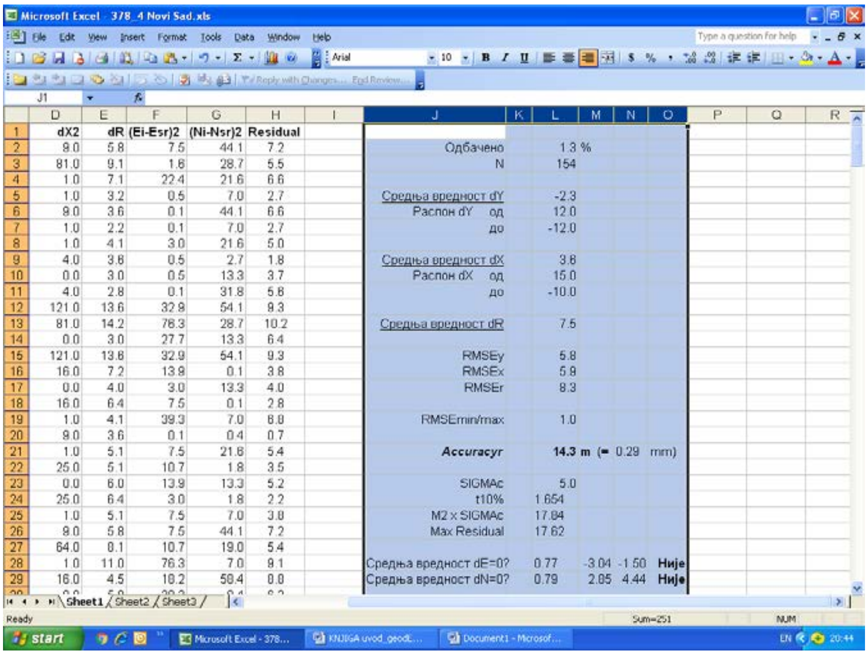

Figure 5. *Excel worksheer for calculating the statistics*

3.3. ASSESSMENT OF VERTICAL ACCURACY

The vertical accuracy has not been assessment according to NSSDA because 1: 50.000 topographic map users have access to a digital elevation model that allows them to determine altitudes with better accuracy than the accuracy of height measurements on the map.

4. CONCLUSION

The US National Standard for Spatial Data Accuracy is a simple and low demanding standard, but very efficient one. It can be preferable standard for acccuracy assessment in Military Geographical Institute, but few smaller improvements have to be done.

The first of all, the minimal sample of well-defined points per sheet must be some larger, ie. 25-30 instead of 20. Then, well-defined point have to belong to all types of uniformly distributed geographic elements. And final, the coordinate differences of measured and reference coordinates must be tested for outliers. Those are the basic improvements, noticed during implementation NSSDA on topographic map 1:50.000 made by MGI.

The analysis of the horizontal positional accuracy of this topographic map shows that this map has an accuracy that meets the most modern accuracy requirements, regardless of the fact that the content and technology used to make the map are three decades old.

This research confirmed the need to assess the geometric accuracy of a map immediately after its production, in line with the dynamics of its production, before giving it to users. In this way, possible problems with accuracy could be analyzed and eliminated, and the assessment of accuracy could be communicated to the user. In addition, the content of the map would be more up-to-date and it would be easier to choose well-defined points.

Field measurements could be used to improve the positional accuracy of MGI vector maps, as well as to be used for future accuracy and accuracy assessments of other large-scaled maps.

LITERATURE

[1] The International Organization for Standardization, „ISO19113: Geographic information – Quality principles“, Genève 2000.

[2] Federal Geographic Data Committee / Subcommittee for Base Cartographic Data, „Geospatial Positioning Accuracy Standards: Part 3 : National Standard for Spatial Data Accuracy“. Internet: https://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part3/chapter3,1998. [Dec. 22, 2021]

[3] C. R. Greenwalt and M. Z. Shultz, „Principles of error theory and cartographic applications“, ACIC Tehnical report No. 96, US Air Force: Aeronautical Chart and Information Center, St. Louis, Missouri, 1968.

[4] NATO, „Standardization Agreement (STANAG) 2215 : Evaluation of Land Maps, Aeronautical Charts and Digital Topographic Data“, NATO Standardization Agency, Brussels, 2002.

[5] B. Bozic and S. Radojcic, „Horizontal Accuracy of 1:50 000 DigitalTopographic Maps“. *Survey Review*, vol. 43(319), pp.94–104, 2011.

[6] Z. Mladenovski, „Automatska digitalizacija topografske karte razmera 1: 25.000, *Zbornik radova Vojnogeoografskog instituta*, Vol. 11, pp 153-159, Beograd, 2003.

[7] M. Peterca, N. Radošević, S. Milisavljević, F. Racetin,“Kartografija“, Vojnogeografski institut, Beograd, 1974.

[8] S. Radojčić, „Analiza horizontalne položajne tačnosti digitalne karte 1:50.000 izdanja Vojnogeografskog instituta“, PhD Thesis, Military Academy, Beograd, 2008.

[9] G.E.P. Box, J. S. Hunter and W.G Hunter, „Statistics for Experimenters : Design, Innovation and Discovery“, Wiley, New York, 2005.