EVALUATION OF POSITIONAL ACCURACY OF DIGITAL TOPOGRAPHIC MAPS AT SCALE 1:25 000 (DTM25) ON THE BASIS OF STANAG 2215 STANDARD

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Abstract:

The paper describes the results of the positional accuracy assessment of digital topographic maps at scale 1: 25 000 produced by the Serbian Military Geographic Institute (MGI). The test for the horizontal and vertical accuracy compliance of map sheets is done by comparing the planimetric and height coordinates of the ground points to the coordinates of the same points as determined by a check survey of higher accuracy. In this research STANAG 2215 standard was used and the methodology of its use is discussed in detail. The results of positional accuracy assessment for the digital topographic maps at scale 1:25 000 produced by the Military Geographic Institute have confirmed the highest level of accuracy defined by STANAG 2215 standard.

Key words: positional accuracy, STANAG 2215 standard, digital topographic maps, Military Geographical Institute.

Introduction

Positional accuracy represents the nearness of those values to the entity`s "true" position in the coordinate system (Drummond, 1995), (Tveite, 1999). Positional accuracy is one element of the spatial data quality, which

is defined as the accuracy of the position of features within a spatial reference system (Stanislawski et al, 1996), (Zandbergen, 2008), (Drobnjak et al, 2016). Also, positional accuracy may be defined as a degree to which the digital representation of a real-world entity agrees with its true position on the earth's surface (Congalton & Plourde, 2002), (Devillers & Jeansoulin, 2010).

It consists of three sub-elements of data quality:

- Absolute or external accuracy – closeness of the reported coordinate values to the values accepted as or being true;
- Relative or internal accuracy – closeness of the relative positions of features in a dataset to their respective relative positions accepted as or being true;
- Positional accuracy of gridded data – closeness of the gridded data spatial position values to the values accepted as or being true.

Evaluation of positional accuracy is reduced to a comparison of the coordinates of individual points read from maps with a reference, several times more accurate coordinates of the same points positioned corresponding geodetic measurements in the field, or taken from other sufficiently accurate sources (Goodchild & Hunter, 1997). The basic problem in assessing the positional accuracy of the maps is the choice of measures of accuracy (i.e. accuracy estimators), as well as a corresponding set of points that represent a particular map sheet and that represent entirety of whole map (Bozic & Radojcic, 2011), (Petrovič, 2006).

An example of successful positional accuracy estimation of digital topographic maps is represented by the Army Geographic Institute of Portugal, who has made the assessment of the positional accuracy of a vector data digital topographic map at scale 1:25 000 using STANAG 2215 standard. In the article (Afonso et al, 2006), the obtained results of estimates of positional accuracy are divided into specific areas by the year of production of spatial data, as it was done in this paper.

Positional accuracy has traditionally been evaluated using control points. These points are defined as "well defined points", and their use has been conditioned by classical topographic field surveying methods (Bozic & Radojcic, 2011). Following this idea, there are very many statistical Positional Accuracy Assessment Methodologies like: NMAS, NSSDA (FGDC 1998), STANAG 2215 (NATO 2002). Also, those methodologies represent point-based positional accuracy assessment methods and many of them are stated as standards for the positional control of cartographic products by national mapping agencies. Some of these methods have recently been analyzed in detail using a simulation process and compared in a more general manner by the same authors. Nevertheless, researchers have criticized these standards for being limited to well defined points, and

also for failing to address more complex elements like linear and polygon ones. It is not possible to assume that all features can be characterized by an error in the position of the well-defined points (Bozic & Radojcic, 2011).

On the other hand, the most widely applied methods for the line-based positional accuracy assessment of 2D lines are: the Hausdorff Distance (HDM) (Ariza-López et al, 2011), the Mean Distance (MDM) (Skidmore & Turner, 1992), the Single Buffer Overlay (SBOM) (Goodchild & Hunter, 1997) and the Double Buffer Overlay (DBOM) (Tveite, 1999). All the methods present an asymmetric or directional behavior which means that results depend on the direction of the assessment. The asymmetry comes from intervening elements in the distance estimation formula being applied. All the results are understood as uniform errors along the lines but we know that the distribution is non-uniform in lines; and that is a limitation of all of them.

Figure 1 shows two examples of errors in the evaluation of positional accuracy of the test data set. Section 1 shows a road portion which is wrong mapped, while Section 2 shows a public object in the scale (hospital), also mapped at wrong positioning in relation to the reference data of the universe of discourse.
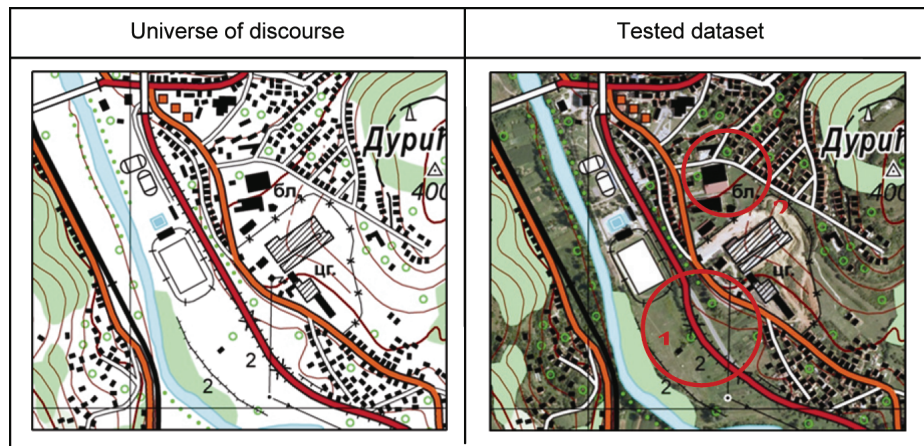

Figure 1 – Example of positional inaccuracy
Рис. 1 – Пример позиционной погрешности
Слика 1 – Пример положајне нетачности

Methods and materials

In STANAG 2215, the absolute horizontal accuracy is defined as the uncertainty in the horizontal position of a point with respect to the

horizontal datum required by a product specification, caused by random and any systematic errors, and is expressed as a circular error at the 90% confidence level – CMAS (NATO, 2002). In a similar manner, the absolute vertical accuracy is defined as the uncertainty in the vertical position of a point with respect to the vertical datum, caused by random and any systematic errors, and is expressed as a linear error at the 90% confidence level – LMAS (NATO, 2002).

The process of evaluation of horizontal positional accuracy begins with the first step, where we calculate the circular error or circular error estimate – CE (defined as the distance in the horizontal plane between a true or known position and the measured or derived position and may involve the use of several circular error confidence levels). The circular error takes into consideration that a certain percentage of the error in the two axes E (Easting coordinates) and N (Northing coordinates) will lie within a circle of a certain radius of the mean error (Ariza López & Atkinson, 2008). The circular standard deviation of the measured differences between the product and reference data sets, marked with σ_C may be computed from the linear standard deviations of E and N (NATO, 2002):

$$\sigma_C \sqrt{\frac{\sigma_E^2 + \sigma_N^2}{2}} = \sqrt{\frac{1}{2} \cdot \left[\frac{\sum \left(\delta E_i - \overline{\delta E} \right) + \sum \left(\delta N_i - \overline{\delta N} \right)^2}{n - 1} \right]} \qquad (1)$$

where
- σ_C is the circular standard deviation (with a confidence level of 39.35%),
- δE_i, δN_i are individual differences of measured and reference coordinates of the E and N axis, respectively,
- $\overline{\delta E}$ and $\overline{\delta N}$ are the arithmetic means of the difference between the axes and
- n is the number of the diagnostic points.

Then the outlier detection is performed. The residuals R with a value higher of $M_2 \cdot \sigma_C$, should be tested according to:

$$R = \sqrt{\sum \left(\delta E_i - \overline{\delta E} \right)^2 + \sum \left(\delta N_i - \overline{\delta N} \right)^2} > M_2 \cdot \sigma_C \qquad (2)$$

where M_2 is computed depending on the size of a sample (i.e. degrees of freedom, $n–1$):

$$M_2 = \sqrt{2.5055 + 4.6052 \cdot \log_{10}(n-1)} \qquad (3)$$

STANAG 2215 standard regulates a test to determine whether or not a computed bias is significant, by compare values of δE and δN with zero. The bias should be considered to be significant at the 90% confidence level if zero does not lie in the range $\left(\overline{x} - t_{10\%} \cdot \sigma_{\overline{x}}\right)$ and $\left(\overline{x} + t_{10\%} \cdot \sigma_{\overline{x}}\right)$, where:

– $\sigma_{\overline{x}} = \dfrac{\sigma_x}{\sqrt{n}}$

– $\overline{x}$ – mean value along the axis E or N ($\overline{\partial E}$ or $\overline{\partial N}$)

– σ_x – root-mean-square error per coordinate axis, E or N

– $t_{10\%}$ – value which ensures a confidence level of 90% based on a t distribution for n–1 degrees of freedom.

The absolute horizontal accuracy at the 90% confidence level when there is no systematic error (i.e. when $\overline{\partial E}$ and $\overline{\partial N}$ do not significantly differ from zero) is calculated with (NATO, 2002):

$$CMAS = 2.146 \cdot \sigma_C \tag{4}$$

When the products contain a bias (i.e. when $\overline{\partial E}$ and/or $\overline{\partial N}$ significantly differ from zero), then:

$$CMAS = \sigma_C \cdot \left[1.2943 + \sqrt{\left(\dfrac{d}{\sigma_C}\right)^2 + 0.7254}\right] \tag{5}$$

where d is the mean error vector (bias):

$$d = \sqrt{\left(\overline{\partial E}\right)^2 + \left(\overline{\partial N}\right)^2} \tag{6}$$

In accordance with STANAG 2215, map products at scale 1:25000 are classified by the CMAS in five position accuracy classes (Table 1).

Table 1 – The cartographic products classification by horizontal positional accuracy
Таблица 1 – Классификация картографических изданий по горизонтальной позиционной точности
Табела 1 – Класификација картографских публикација на основу хоризонталне положајне тачности

Rating	Measurement at Product Scale	Value of Circular Map Accuracy Standard (CMAS)
A	0.5 mm	12.5 m
B	1.0 mm	25 m
C	2.0 mm	50 m

Rating	Measurement at Product Scale	Value of Circular Map Accuracy Standard (CMAS)
D	>2.0 mm	Poorer than Rating C
E	Not determined	

For vertical accuracy evaluation, STANAG 2215 demands at least 167 check points per data set, like for horizontal accuracy evaluation. In the vertical accuracy evaluation procedure, the first step is to calculate the height differences between the measured height and the reference height δH_i, then its differences from the mean value of all differences and calculate the linear standard deviation:

$$\sigma = \sqrt{\frac{\sum \left(\partial H_i - \overline{\partial H}\right)^2}{n-1}} \tag{7}$$

Then, the tests for blunders and systematic errors are performed, in the same way as for horizontal accuracy evaluation. Finally, we have to evaluate the linear error with the 90% confidence level. If ∂H is not significantly differing from zero, the LMAS is calculating as:

$$LMAS = 1.645 \cdot \sigma \tag{8}$$

and in the opposite case:

$$LMAS = \sigma \cdot \left[1.645 + 0.92 \cdot \left(\frac{\left|\overline{\partial H}\right|}{\sigma}\right)^2 - 0.28 \cdot \left(\frac{\left|\overline{\partial H}\right|}{\sigma}\right)^3 \right] \tag{9}$$

By the value of the LMAS, STANAG 2215 divides all cartographic products at scale 1:25 000 into five classes (Table 2).

Table 2 – The cartographic products classification by vertical positional accuracy (α=0.10)
Таблица 2 – Классификация картографических изданий по вертикальной позиционной точности (α = 0,10)
Табела 2 – Класификација картографских публикација на основу вертикалне положајне тачности (α=0,10)

Rating	Value of Linear Map Accuracy Standard (LMAS)
0	2.5 m
1	5 m
2	10 m
3	Poorer than Rating S
4	Not determined

111

STANAG 2215 standard requires a minimum of 167 diagnostic (well-defined) points per sheet or a defined test area. In this standard, the assessment of the accuracy is also based on comparisons between the values on the product being assessed and more accurate data. A well-defined point is one that can be easily and uniquely identified on the map and in the field. STANAG 2215 insists that all types of geographic elements must be involved (Bozic & Radojcic, 2011).

In this research, the test area for the positional accuracy assessment was covered by 49 sheets of a digital topographic map at scales of 1:25 000 (DTM25), as shown in Figure 2. The marked rectangles in Figure 2 represent the tested sheets of the digital topographic maps at scale 1:25000.

For every sheet of DTM25 in the test area, we assigned to the 167 well-defined points, chosen from nearly all thematic layers of digital topographic maps. A larger number of those points are collected in the field measurement using a GPS receiver, while the coordinates of remaining points are determined using 3D stereorestitution (Drobnjak et al, 2014).

The field measurements were carried out with one GPS Trimble Geoexplore receiver. The receiver was tested on control points. The accuracy of the GPS positioning in the national map grid system, as defined by the root mean square error of a single point, was 1.41 m. The coordinates obtained by GPS measurements and 3D stereorestitution were compared with the map coordinates of the common points using the PAAT (Positional Accuracy Assessment Tool) tool ESRI ArcGIS software (Esri ArcGIS, 2014).
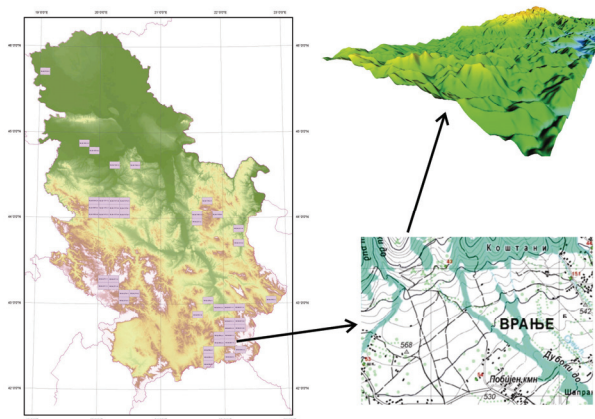

Figure 2 – Test area for positional accuracy assessment
Рис. 2 – Местность тестирования, выбранная для оценки позиционной точности
Слика 2 – Тест-подручје за оцену положајне тачности

The PAAT tool used the root mean square error, which is denoted by RMSE for assessing the positional accuracy. RMSE is the second root of the mean sum of squared differences of coordinates read from the map and the corresponding reference ("true") coordinates. The absolute horizontal accuracy is the uncertainty of two-dimensional position (relative to the horizontal datum) and is expressed as circular errors with 90, 95 and 99% confidence levels. On the other hand, absolute vertical accuracy is the uncertainty of one-dimensional position (relative to the vertical datum) and is expressed as a linear error with 90, 95 and 99% confidence levels. Accuracy is communicated in those units in which coordinates are expressed in nature (meter), which enables a direct comparison of different products, regardless of the differences in scale or resolution.

The PAAT has the ability of the automatic testing and elimination of gross errors. A testing statistic called 3σ threshold is used for this (Figure 3). If a specific positional error is greater than the value of 3σ, the program eliminates it, leaving the possibility to keep these points if we wish to do that (ESRI, 2012).
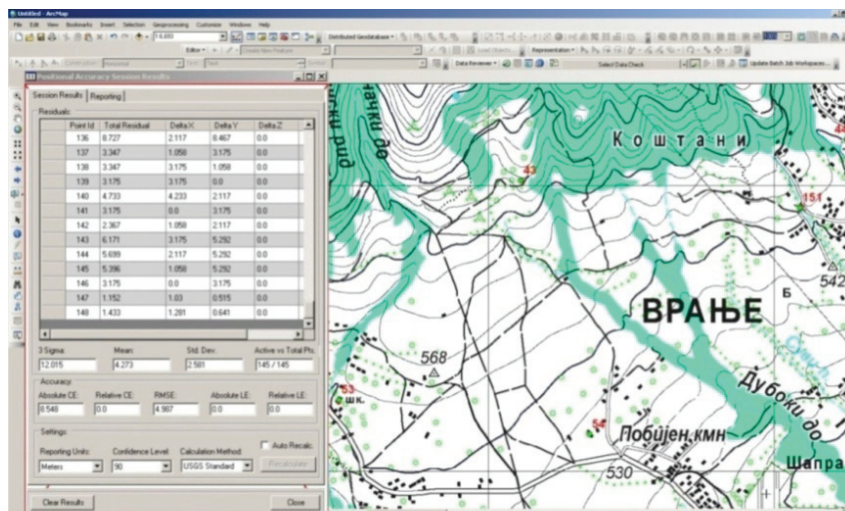

Figure 3 – PAAT tool
Рис. 3 – Инструмент РААТ
Слика 3 – Алат РААТ

The report of the positional accuracy assessment results using the PAAT tool consists of a text file for the appropriate test area, the vector data of the reference and the test points in a standard ESRI Shapefile vector format and metadata in accordance with ISO 19115 and FGDC standards in the form of an XML file. Since the PAAT tool does not have

an integrated analysis of positional accuracy on the basis of STANAG 2215 standard, the results of the analysis have been exported to the Excel format (Drobnjak et al, 2016).

Results

Table 3 shows the results of an analysis of the absolute positional accuracy of using the aforementioned quality measures with classification of digital topographic maps according to STANAG 2215 standard for all test areas that were analyzed in the experimental research activities by year of production of spatial data.

Table 3 – Positional accuracy assessment results of the tested area
Таблица 3 – Результаты оценки позиционной точности на тестируемой местности
Табела 3 – Резултати оцене положајне тачности тест-подручја

Ord. num	Test area/map sheet	Results of positional accuracy assessment			
		standard STANAG 2215			
		CMAS	LMAS	Classification related to CMAS	Classification related to LMAS
1	Šira okolina Ljiga (ukupno 8 listova DTK25)	9.111	2.456	A	0
2	NL 34-11/7-4-1 Rudnik	10.715	2.046	A	0
3	NL 34-11/7-4-3 Gornji Milanovac	9.696	1.964	A	0
	mean value =	9.841	2.226		
4	NL 34-11/9-2-3 Žagubica	10.042	2.102	A	0
5	NL 34-11/9-3-4 Resavica	11.387	2.351	A	0
6	NL 34-11/9-4-4 Zlot	10.449	2.452	A	0
7	NK34-2/3-1-2 Zabrega	10.334	2.326	A	0
8	NK34-3/1-1-4 Zaječar	8.193	1.109	A	0
9	NK34-3/1-3-4 Minićevo	9.287	2.021	A	0
	mean value =	9.949	2.060		
10	NL34-10/3-2-3 Hrtkovci	9.221	0.789	A	0
11	NL34-10/3-4-2 Grabovci	8.505	1.061	A	0
12	NK34-5/6-2-2 Moštanica	10.605	2.785	A	1
13	NK34-5/6-2-4 Vranje	7.785	2.428	A	0
14	NK34-5/6-4-1 Bujanovac	10.304	1.617	A	0
15	NK34-5/6-4-3 Biljača	9.178	1.578	A	0
16	NK34-5/9-2-1 Žujince	9.253	1.654	A	0
17	NK34-6/4-3-2 Dukat	12.195	4.805	A	1
18	NK34-6/4-1-1 Jelašnica	8.402	1.995	A	0
19	NK34-6/4-1-3 Bujkovac	9.253	3.197	A	1
20	NK34-6/4-3-3 Trgovište	9.335	2.465	A	0
	mean value =	9.458	2.216		
21	NK34-2/9-4-3 Bojnik	7.468	0.690	A	0
22	NK34-3/8-3-3 Dimitrovgrad	7.276	1.247	A	0
23	NK34-5/3-1-4 Medveđa	9.751	2.415	A	0
24	NK34-5/3-2-2 Leskovac	7.675	0.679	A	0
25	NK34-6/1-1-1 Vlasotince	7.503	1.252	A	0
26	NK34-6/1-1-2 Kruševica	8.069	2.425	A	0

	Results of positional accuracy assessment			
		standard STANAG 2215		
27	NK34-6/1-3-1 Predajane	7.909	2.238	A	0
28	NK34-6/1-3-2 Crna Trava	7.857	2.309	A	0
29	NK34-6/1-3-3 Vladičin Han	11.251	2.410	A	0
30	NK34-6/1-3-4 Surdulica	7.999	2.633	A	1
	mean value =	8.276	1.830		
31	NK34-2/7-1-1 Sjenica istok	8.540	1.226	A	0
32	NK34-2/7-1-2 Muhovo	9.176	3.009	A	1
33	NK34-2/7-1-3 Žitniće	8.319	1.103	A	0
34	NK34-2/7-1-4 Bele Vode	8.940	1.893	A	0
35	NK34-2/7-4-1 Mur	9.313	2.266	A	0
36	NK34-2/7-4-2 Novi Pazar	9.606	2.339	A	0
37	NK34-2/7-4-3 Kožilje	8.215	2.237	A	0
38	NL34-11/4-1-2 Obrenovac	6.872	0.716	A	0
39	NL34-11/4-2-2 Ripanj	7.117	0.944	A	0
40	NL34-7/2-4-3 Prigrevica	8.173	0.774	A	0
	mean value =	8.427	1.651		
	Legend:		- Production year 2007		
			- Production year 2009		
			- Production year 2012		
			- Production year 2013		
			- Production year 2014		

From Table 3, it can be concluded that all 40 test areas analyzed in the experimental study of the horizontal positional accuracy of the DTM have a value of the circular error as the map accuracy standard is less than 12.5 meters (CMAS < 12.5 m) and belong to the best "A" map class according to the classification of STANAG 2215 standard. Also, it can be concluded that, in the analysis of the vertical positional accuracy of the 40 analyzed test areas, 35 test areas have a value of linear errors as the map accuracy standard of less than 2.5 meters (LMAS < 2.5 m) and belong to the best "0" map class according to the classification of STANAG 2215, while five test areas have a LMAS value between 2.5 and 5 meters (2.5 m<LMAS<5 m) and belong to the class "1" according to the classification of STANAG 2215. From everything shown and mentioned, it can be concluded that the analyzed DTM produced by the MGI have a high level of geometrical, positional accuracy.

The graphical representation as a diagram of the circular error value as the map accuracy standard (LMAS) by a production year is shown in Figure 4.
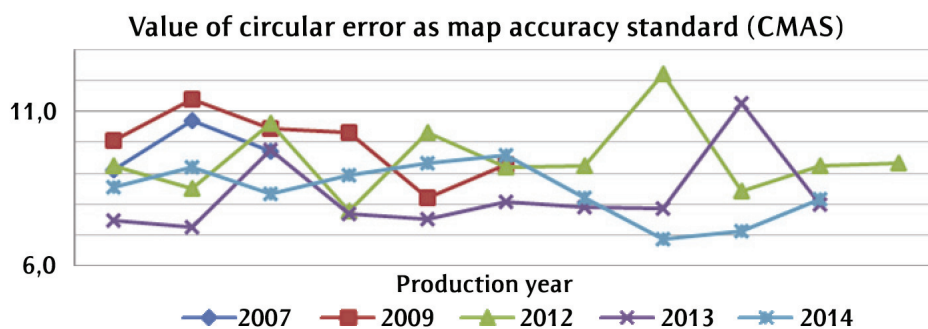
Value of circular error as map accuracy standard (CMAS)

Figure 4 – Diagram of the CMAS values
Рис. 4 – Диаграмма значений CMAS
Слика 4 – Дијаграм вредности CMAS

The graphical representation of the LMAS value by a production year is shown in Figure 5.
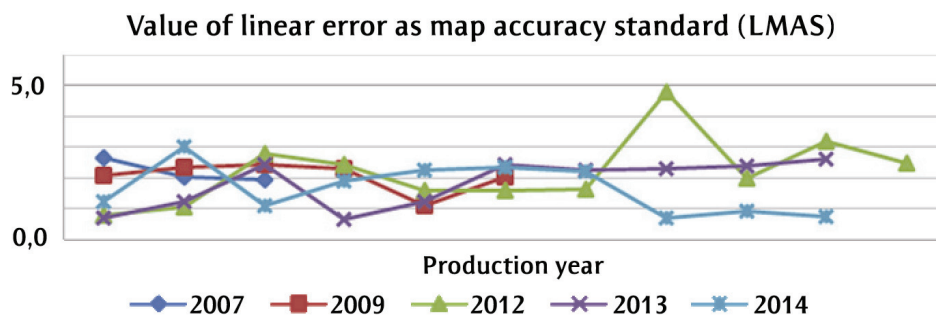
Value of linear error as map accuracy standard (LMAS)

Figure 5 – Diagram of the LMAS values
Рис. 5 – Диаграмма значений LMAS
Слика 5 – Дијаграм вредности LMAS

Table 4 shows the standardized report on the results achieved by positional accuracy assessment and the classification of digital topographic maps related to STANAG 2215 standard for the test area which covers one sheet of DTM25, nomenclature NK34-5/6-2-4, Vranje.

Table 4 – Standardized report of a positional accuracy assessment for the tested area
Таблица 4 – Стандартизованный отчет о позиционной точности на тестируемой местности
Табела 4 – Стандардизовани извештај оцене положајне тачности тест-подручја

DATUM				1/SCALE	25000
INPUT DATA					
			Lower	**MPV**	Upper
Mean E difference =			-1.6636	**-1.2341**	-0.8047
Mean N difference =			0.7770	**1.2712**	1.7654
Mean H difference =			-0.2803	**-0.0920**	0.0963
Standard deviation E =			3.0895	**3.3653**	3.7005
Standard deviation N =			3.5552	**3.8726**	4.2583
Standard deviation H =			1.3548	**1.4758**	1.6228
Circular Standard Error =			3.330	**3.628**	3.989
No. plan points =	**168**		Degrees of Freedom =		**167**
No. height points =	**168**		Degrees of Freedom =		**167**
OUTLYING POINT CHECK					
Circular Tolerance:	12.9497				
Tolerance for E diff:	10.7284		-11.962	< E diff <	9.494
Tolerance for N diff:	12.3455		-11.074	< N diff <	13.617
Tolerance for H diff:	4.7047		-4.797	< H diff <	4.613
ANALYSIS					
			Lower	MPV	Upper
HEIGHT:					
Bias-free Estimate of LMAS			2.2286	**2.4275**	2.6693
Linear Point-to-Point Accuracy			3.1517	3.4331	3.7750
(Intermediate quantity b/Sigma)			0.0679	0.0624	0.0567
Significance of Avge H diff:			NO	NO	NO
Absolute LMAS (bias model 1)			N/A	N/A	N/A
Absolute LMAS (bias model 2)			N/A	N/A	N/A
Selected LMAS figure			2.2286	2.4275	2.6693
Adjusted LMAS figure				**2.4266**	
Rating				**0**	
PLAN:					
Bias-free estimate of CMAS			7.1472	**7.7853**	8.5607
Plan Point-to-Point Accuracy			10.1076	11.0101	12.1067
Systematic Shift				1.7717	
Significance of Shift			YES	YES	YES
(Intermediate quantity d/SigmaC)			0.5320	0.4884	0.4441
Absolute CMAS with bias			7.6550	8.2573	8.9949
Selected CMAS figure			7.6550	8.2573	8.9949
Adjusted CMAS figure				**8.2542**	
Rating				**A**	

117

Conclusion

Knowledge of positional accuracy is of fundamental importance both for map users and for manufacturers. Unlike most online properties, its horizontal positional accuracy can be fully examined and quantified in an exact way. This paper presents the results of an assessment of the positional accuracy of digital topographic maps in a scale of 1:25 000 produced in the Military Geographical Institute. The evaluation of positional accuracy verified and confirmed that the analyzed digital topographic maps produced in the Military Geographical Institute have a high level of geometric positional accuracy.

The obtained results of the positional accuracy assessment have the same level of accuracy to the specifications considered in the STANAG 2215 standard, which indicates that the MGI obtains the best classification as defined in STANAG 2215 standard.

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ОЦЕНКА ПОЗИЦИОННОЙ ТОЧНОСТИ НА ЦИФРОВОЙ ТОПОГРАФИЧЕСКОЙ КАРТЕ МАСШТАБА 1:25 000 (ТК25), РАЗРАБОТАННОЙ В СООТВЕТСТВИИ СО СТАНДАРТОМ «STANAG 2215»

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Резюме:

В статье описываются результаты оценки позиционной точности цифровых топографических карт, масштаба 1: 25 000, разработанных сербским Военно-географическим институтом (ВГИ). Испытание на соответствие горизонтальной и вертикальной точности отдельных листов карт осуществляется путем сравнения контурных и высотных координат наземных точек с координатами тех же точек, которые определяются контрольным обзором с более высокой точностью. В данной работе подробно представлена методология применения стандарта STANAG 2215, в соответствии с которым было проведено настоящее исследование. Результат позиционной оценки точности цифровых топографических карт в масштабе 1:25 000, разработанных Военным географическим институтом, подтвердил высокий уровень точности, определенный стандартом STANAG 2215.

Ключевые слова: позиционная точность, стандарт STANAG 2215, цифровое топографические карты, Военно-географический институт.

ОЦЕЊИВАЊЕ ПОЛОЖАЈНЕ ТАЧНОСТИ ДИГИТАЛНЕ ТОПОГРАФСКЕ КАРТЕ У РАЗМЕРИ 1:25 000 (ДТК25) НА ОСНОВУ СТАНДАРДА СТАНАГ 2215

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Сажетак:

У раду се описују резултати оцењивања положајне тачности дигиталних топографских карата у размери 1:25 000, произведених у Војногеографском институту (ВГИ) Републике Србије. Тестирање хоризонталне и вертикалне положајне тачности појединачних листова карата урађено је поређењем планиметријских и висинских координата тест-тачака са кореспондентним тачкама веће тачности одређених теренским премером. У истаживању је коришћен стандард STANG 2215 и детаљно је описана његова методологија. Резултати овог оцењивања потврдили су највиши ниво тачности дефинисан стандардом STANAG 2215.

Кључне речи: положајна тачност, стандард STANAG 2215, дигиталне топографске карте, Војногеографски институт.

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