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Vector Cadastral Maps Numerical Homogeneity Analysis

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ABSTRACT. In the cadastre of real estates in Slovakia, there is a variety of data of different origin as well as different quality. One of the main problems is the quality of cadastral maps. More than a half of these maps do not meet today's requirements for the recording of real estates and their renewal is needed. This article deals with a homogeneity analysis, which is the first stage of the renewal of a vector cadastral map numerical. Cadastral map numerical should be the best, because it is made of coordinates, which are the result of a numerical measurement but in some of them there are various local deformations. In locations with deformations, there are objects in the POINTS layer where the coordinates of the points determined via GNSS are stored. The first stage of the renewal of these maps is an analysis of homogeneity. This stage is very important because it is necessary to understand how the local deformations behave in the whole cadastral unit and in which parts the renewal is needed. The analysis consists of considering the number of objects in the POINTS layer, selection of the locations with the local deformations, calculating the size and direction of the local deformations in chosen points and comparing the locations with each other. The homogeneity analysis leads to particular methods for the renewal of a cadastral map numerical. This solution for the next stages of the renewal is specific for each cadastral unit.

Keywords: vector cadastral maps, local deformations, transformation, map homogeneity, parameters of map quality, terrain measurements.

1. Introduction

The cadastre of real estates (hereinafter referred to as "the cadastre") is the geometrical determination, registration and description of real estates. The cadastre in the Slovak Republic is currently regulated by the Act of the National Council of the Slovak Republic No. 162/1995 (Act no. 162/1995 Coll.). Cadastral documentation consists of a file of geodetic information and a file of descriptive

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information. Its content and structure are defined by executive regulation (Decree no. 461/2009 Coll., Gašincová and Gašinec 2011). The cadastral documentation is arranged by cadastral units. The main part of the geodetic information file is a cadastral map, which is a large scale planimetric map. The main purpose of a cadastral map is the displaying of real estates. Nowadays, these maps are drawn up in Kŭovák's conformal conic projection with the coordinate system – System of the Unified Trigonometrical Cadastral Network (hereinafter referred to as "UTCN").

There is a huge variety of graphical data of different origin and different quality in Slovakia (Seidlová and Chromčák 2017). The quality of cadastral maps is a topic discussed for a long time (Horňanský et al. 2014a, Hudecová 2011). However, the low quality of cadastral maps is not just a problem of the Slovak Republic, but also of many other countries (Kaufmann et al. 2009, Buśko and Meusz 2014, Moharić et al. 2017, Hanus et al 2018, Popov 2019, Zrinjski et al. 2019). Since 2013, one parameter for monitoring the quality of cadastral maps is used, which is the quality code of points. One of the five quality codes can be assigned to a point according to its origin and precision of its determination (Decree no. 461/2009 Coll.). This system for monitoring the quality of cadastral maps is very limited, so six new indicators of quality were proposed (Kyseľ et al. 2018, Kyseľ 2019). Three of them are related to the map as a whole and another three are related to the individual plots on the map. One of these indicators of quality is homogeneity of a map, which this paper deals with. This indicator is one of the most difficult to determinate because it does not result from the parameters and precision of the original measurements and it can be determined just by a detailed analysis of a map with the use of different types of terrain measurements.

2. Cadastral maps numerical

In the cadastre, there is a variety of data of different origin and quality. This article deals only with the analysis of a vector cadastral map numerical (hereinafter referred to as "VCMn"). This type of maps represents the better part of the cadastral map collection (43% of maps).

2.1. The quality of cadastral (original) maps numerical

The quality of maps is assessed according to the accuracy of the maps. Accuracy is given by standard error values and limit deviations, which are the criteria for punctuality according to STN 01 3410 (STN 1990).

Cadastral maps numerical are drawn up in a System of the Unified Trigonometrical Cadastral Network. Geometric base for the map consists of geodetic controls points (STN 2010). The main characteristic of the positional accuracy of a detailed point on the map is a mean coordinate error m_{xy} (1), where m_x and m_y are the mean errors of the position in the direction of the coordinate axis x and y:

$$m_{xy} = \sqrt{0.5\,(m_x^2 + m_y^2)}. \tag{1}$$

Before 1995, when the cadastral maps were only in the paper form, the detailed points had to be displayed in such a way, that the mean coordinate error m_{xy} did not exceed the value of 0.16 mm on the map.

Relative accuracy of detailed points is given by the basic standard error of length m_d directly connecting the points, which is calculated from coordinates. Coordinates of detailed points must be determined so that:

- characteristics of m_{xy} do not exceed criterion u_{xy} (Table 1)
- characteristics of m_d do not exceed criterion u_d (2)

$$u_d = 1.5\,\frac{(d+12)}{(d+20)}\,u_{xy}. \tag{2}$$

Table 1. *The class of precision (STN 1990).*

The class of precision	u_{xy} (m)
1.	0.04
2.	0.08
3.	0.14
4.	0.26
5.	0.50

Precision of the mapping is divided into precision classes 1–5. Cadastral maps (1927–2009) were made in the 3rd or 4th class of precision. Fourth class of precision was used for example in mapping forest land or using photogrammetric mapping method. Cadastral maps (since 2009) are made in the 2nd class of precision (Table 1).

2.2. The quality of cadastral (derived) maps numerical

The oldest cadastral maps are from 1927. During their existence, there have not been made any larger modifications of these maps which would massively impact their quality and precision but original paper cadastral maps have been repeatedly updated and re-drawed. During that time, the technologies limited the accuracy of the measurements and displaying in the map as the approach was very subjective (Horňanský et al. 2014b). Only step by step, with the help of automatization, the influence of human factor has been decreasing (Hudecová 2017). The quality of cadastral (derived) maps cannot be determined.

2.3. Vector cadastral maps numerical (VCMn) and their updating

All the cadastral maps were gradually replaced by vector maps between 1995 and 2015. These maps are updated interactively using vector geodetic designs

(Raškovič et al. 2019). If a new measurement is performed, the positional deviation between the position of the original point on the map and the position of the point determined within our measurement should be less than 0.24 m (Gašincová et al. 2014).

In some of the VCMn, there are locations, where the positional deviation is greater than 0.24 m, but at the same time this positional deviation is systematic in all the points in the location, which means that the direction and the size of the offsets are similar in all the points. In the process of updating this type of VCMn, a special procedure for the creation of vector geodetic design is applied (Decree no. 461/2009 Coll., Guideline 2013). In this procedure, all the points with coordinates in the coordinate system UTCN are transformed into the map by a local transformation. The points, which are the result of the new measurement, are stored in one object in the POINTS layer. All the points in this object are assigned a quality code value 1 and a symbol no. 1310 " ⊕ ".

The quality of vector cadastral maps is a function of the date of its creation (the date of mapping) and it decreases with time.

Since 2009 we use GNSS technology for determining the position of detailed points. This technology is independent and the results of the measurement are reliable, which means that the new measurements are correct, and they do not cause errors in the map.

3. Analysis of VCMn in the cadastral unit of Hlohovec

For this article, the cadastral unit of Hlohovec has been chosen.

Cadastral unit: Hlohovec (816 248)
Region Nomenclature of Units for Territorial Statistics – NUTS3: Trnavský
District (Local Administrative Unit – LAU1): Hlohovec (203)
Area: 47,229,330 m^2

3.1. Characteristics of the cadastral map in the chosen location

The cadastral mapping was performed in 1987 and it was regulated by the Instruction which was published in 1981 (Instruction 1981). This instruction is in force up to this day with some minor modifications. The measurements were performed using the terrestrial methods. The measurements ought to have been connected to the passive geodetic controls, which consisted of State trigonometric network and the detailed points network (with permanent or temporal point monumentation). All detailed points in the urban area were determined in the 3rd class of precision with positional accuracy 0.14 m (Table 1). This precision refers to the geodetic controls.

The documentation of new mapping and all the measurements performed in the cadastral unit since 1987 are stored in the cadastral office. The VCMn in Hlohovec was approved in 2004.

If we perform a new measurement in this cadastral unit, the positional deviations Δp in all the detailed points should be less than 0.24 m, according to (3):

$$\Delta p \leq 1.7 \cdot m_{xy}. \quad (3)$$

Since 2013 the POINTS layer is included in the vector geodetic design which contains the measured coordinates, if measurements had shown the local deformations (Fig. 1). For the purpose of updating the VCMn, these coordinates are transformed using the local transformation (Guideline 2013). Local deformations appeared after 2009, when it became compulsory for the surveyors to use active geodetic controls.

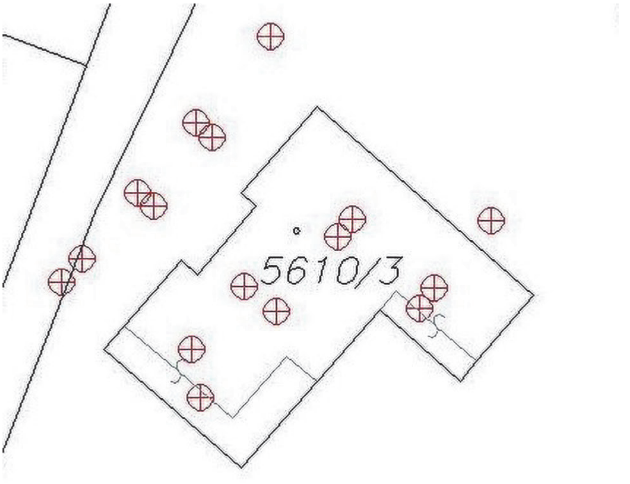

Fig. 1. *VCMn with the POINTS layer (POINTS layer in red colour).*

3.2. Draft principles of methodology of testing the homogeneity of the VCMn

Analysis of VCMn is necessary if new measurements show homogeneity errors. In these cadastral units with VCMn, there will not be any cadastral mapping within the next few years because of financial reasons. Size of local deformations on the map should be qualified and the optimal solutions for the correction of the map are sought. These solutions should minimalize the time and costs of the correction and, at the same time, the results should be reliable. All the results of the previous measurements in the vector geodetic designs should be used effectively to the greatest extent possible.

Testing the homogeneity of the VCMn includes:
- considering the number of objects in vector geodetic designs and the number of vector geodetic designs with the POINTS layer (4.1)
- selecting the locations where the objects in the POINTS layer are mostly concentrated and qualifying the size of positional deviation in each of the selected locations (4.2)
- comparing the size and the direction of local deformations of the individual locations and analysing the reasons for positional deviations (4.3)
- drawing up a solution for renewal of the map (4.4).

4. Results and discussion

4.1. Vector geodetic designs status

Since 1981 approximately 2,150 new geodetic measurements were performed in the cadastral unit (Fig. 2, left side). Approximately in 150 of these cases (approximately 7%), measurement shows local deformation and is included in the POINTS layer (Fig. 2, right side).

Fig. 2. *All vector geodetic designs in the cadastral unit of Hlohovec (left); vector geodetic designs with the POINTS layer included (right).*

The objects in the POINTS layer are mostly concentrated in bigger structures which are scattered over the whole urban area and some of them are also located in the rural area. The areas with the local deformations are not just in one place, but they cover most of the cadastral unit (Fig. 2, right side).

4.2. Selection of locations and qualifying their positional deviation

According to the number of objects in the POINTS layer, three locations (Fig. 2) with local deformations in the cadastral unit were chosen and the size and direction of the local deformations were calculated in these locations. These three locations do not have any evident borders and they are delimited only by the existing objects in the POINTS layer. There were no new measurements performed. Only the existing results of measurements are used.

Location no. 1.

The first tested location is outlined by 6 updates, the content of the POINTS layer is in Fig. 3 displayed in red colour. These updates were measured between 2014 and 2018. The coordinates of the detailed points in the VCMn were compared with the coordinates of the same points in the POINTS layer and the size and direction of the positional deviations were calculated using software "Kokeš". The

Fig. 3. *Location no. 1.*

direction is defined as an azimuth in the UTCN coordinate system and it expresses the direction from the point in the VCMn to the point in the POINTS layer. The positional deviations in chosen detailed points are shown in the Table 2.

Table 2. *Positional deviations in the location no. 1.*

Point number	Positional deviation [m]	Azimuth [gon]
4291-1	0.32	373.1716
56-46	0.33	386.2899
4291-2	0.31	375.0229
4254-3	0.31	360.2735
4254-1	0.31	360.2735
56-190	0.35	359.0334
56-50	0.33	348.6457
……	……	…….
3904-2	0.35	353.8928
3904-5	0.35	353.8928
3765-3	0.35	353.8928
55-247	0.36	357.6031
55-40	0.36	358.6837
3787-2	0.36	358.6837
3838-2	0.30	361.9826
3838-1	0.31	360.2735
Number of chosen detailed points = 15	Average = 0.33	Average = 361.4410
	Standard deviation = 0.02	Standard deviation = 9.8691

Table 2 shows that the size of the positional deviation in 15 chosen examined detailed points in this location is approximately the same. Their average value is 0.33 m. The biggest difference between the values is 0.06 m. The values of the azimuths in the UTCN coordinate system are also approximately the same. Their average value is 361.4410 gon.

It can be said that the local deformations in the whole location have systematic nature, which means that their size and direction is approximately the same. Location no. 1 can be thus considered homogenous.

Location no. 2.

The second location is in the garden colony in the rural area. Three of the updates were analysed in this location. The content of the POINTS layer is displayed in Fig. 4 in red colour. The updates were measured in 2015 and 2016.

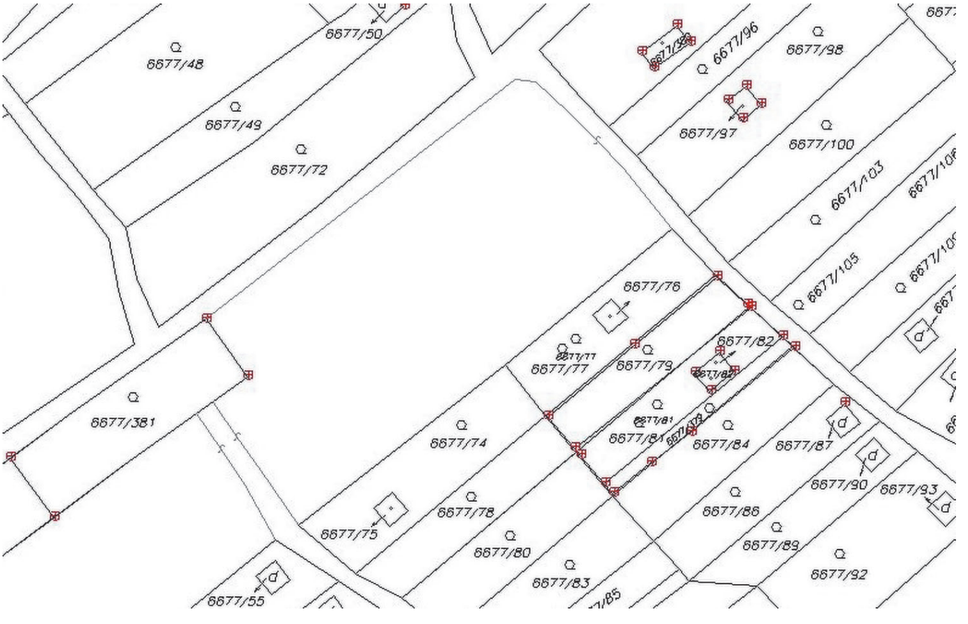

Fig. 4. *Location no. 2.*

The size and the direction of positional deviations in chosen detailed points are shown in Table 3.

Table 3 shows that the values of size of positional deviations and also the azimuths of positional deviations are similar. Location no. 2 can also be considered homogenous.

Table 3. *Positional deviations in the location no. 2.*

Point number	Positional deviation [m]	Azimuth [gon]
3950-2	0.50	237.4334
3950-3	0.50	237.4334
1400-686	0.52	239.4863
1400-1176	0.46	235.1194
1400-687	0.55	240.9666
3950-4	0.50	237.4334
1400-1175	0.50	233.5261
……	……	…….
1400-734	0.35	224.5661
3853-13	0.45	233.9219
3853-1	0.46	235.1194
1400-714	0.43	239.4863
3853-2	0.46	235.1194
3453-9	0.45	244.0491
3453-8	0.45	242.9553
3970-1	0.46	234.1704
Number of chosen detailed points = 15	Average = 0.47	Average = 236.7191
	Standard deviation = 0.05	Standard deviation = 4.6858

Location no. 3.

The third location is situated in the urban area (Fig. 5). The analysis concerned three of the updates and the monitored values in location no. 3 are shown in Table 4. The updates were measured in 2014 and 2018.

Fig. 5. *Location no. 3.*

Table 4. *Positional deviations in the location no. 3.*

Point number	Positional deviation [m]	Azimuth [gon]
932	0.57	18.0224
931	0.57	19.4164
170-86	0.58	14.2752
3764-4	0.60	17.1357
3764-1	0.57	14.7762
3764-5	0.60	17.1357
194-32	0.63	17.3028
……	……	…….
194-28	0.63	16.3304
3764-10	0.60	23.8308
3695-1	0.49	5.1854
193-46	0.50	5.0821
4288-9	0.44	7.2034
193-50	0.32	398.0112
193-47	0.44	5.7716
4288-13	0.44	7.2034
Number of chosen detailed points = 15	Average = 0.53	Average = 12.4455
	Standard deviation = 0.09	Standard deviation = 7.1492

The standard deviation for positional deviations in location no. 3 shows that the size of the local deformations is not equal in all the points. The same can be said in case of the direction of local deformations. The values are similar only in some parts of the location but if we consider the location as a whole, the values differ. Their average is 12.4455 gon and their standard deviation is 7.1492 gon. That is why location no. 3 cannot be considered homogenous.

4.3. Local deformations analysis

For the purposes of investigation of the reasons for the local deformations in the monitored locations, the documentation from the original measurement was searched in the cadastral office in Hlohovec. Methods of building of control point network and measurement of detailed points were observed:

a) The first step in the measurement process was to establish a network of control points which served as a geometrical base of the cadastral map. The options were: the points of State Trigonometrical Network (Fig. 6, D), river polygon of the Váh river (Fig. 6, A), the network of points used for the vineyard construction (Fig. 6, B) and road construction (Fig. 6, C).

   In location no. 1: The best solution could be connection of the network to the points of State Trigonometrical Network according to the instruction (Instruction 1981) (Fig. 6, D). However, their layout in this location was very inconvenient and the connection to these points would be very time and finance consuming, so the surveyors have chosen another possibility. They connected the measurement to the points of other networks, such as river polygon of the Váh river.

In locations no. 2 and 3: In these locations, the surveyors also decided not to use the points of State Trigonometrical Network. The measurement was connected mainly to the network of points used for the vineyard construction (Fig. 6, B) and road construction (Fig. 6, C). Essentially, these points have unknown precision, which can be up to 0.50 m. This connection of the network of control points is probably the main reason for the local deformations.

The polygons were measured with Zeiss Theo 010 and Theo 020 theodolites and ELDI 3 distance meter. This equipment used did not have any impact on the precision of the control points.

b) After establishment of the network of points which served as stations for the measurement instruments, the next step was the measurement of detailed points itself. The main measuring methods were polar and orthogonal methods. The polar method was used to determine the position of the detailed points only on the fences around the houses and the orthogonal method was used to determine the position of other detailed points inside the fence. The fence was used as a main survey line, from which the perpendicular lines were

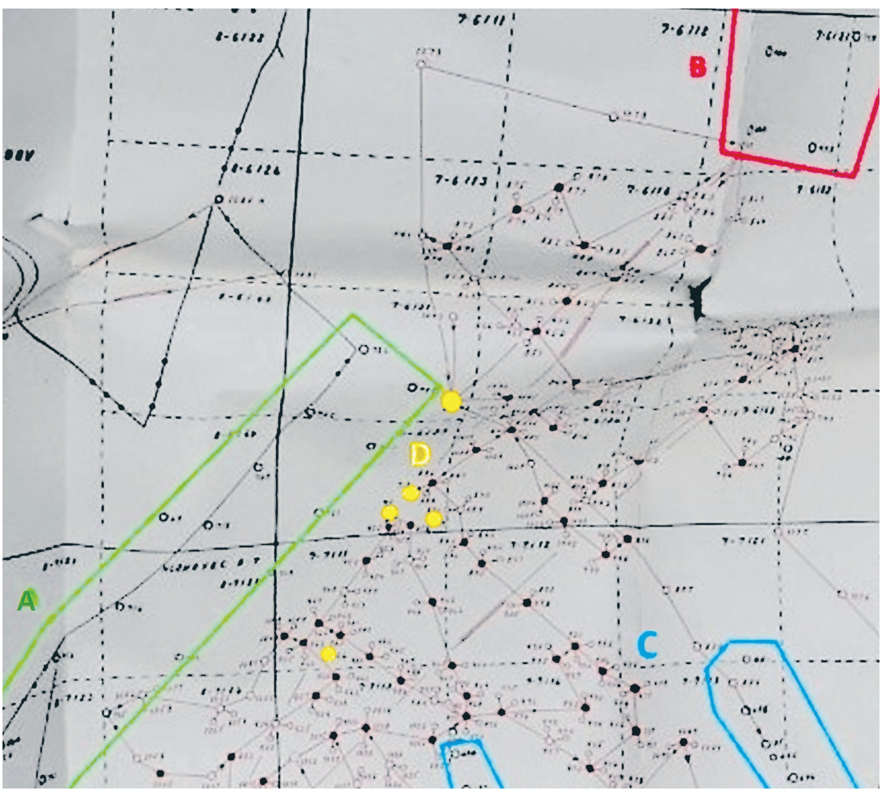

Fig. 6. *Sketch of the control points network in Hlohovec.*

determined, which means that the main survey line was not composed of the points of geodetic controls but of detailed points which were of worse quality.

This technique of measurement did not have any impact on the formation of local deformations in the cadastral map.

c) The surveyors used Zeiss BRT 006 instruments which allowed them to measure horizontal angles and lengths at the same time without any other tools. The precision of a length was given as 0.06% of measured length, which is 4 cm at the maximal length of 60 m. The precision of horizontal angles was much worse. The instrument was equipped with the angle-measuring of a low quality – the smallest division on a horizontal circle was only 50 mgon and the precision of measuring horizontal angles was given as 6 mgon. If we convert this angle in meters, that gives us 32 cm precision on the maximal length of 60 m.

Despite this precision, we presume that the measuring equipment used during the measurement process did not have any impact on the precision of points and could not cause the local deformations on the map.

The most likely cause of the local deformations on the map was that points with essentially unknown precision were used. This assumption is supported by the fact that in the location no. 3, there were points of the geodetic controls network between the measured points no. 931 and no 932; these points are highlighted in Table 4. The positional deviation in these points is 0.57 m, which indicates that some errors could be made during the establishment of the geodetic controls network. However, this assumption cannot be verified nowadays because these control points are destroyed.

We can state that the positional deviations of 3 monitored locations were caused by the methods of establishing the network of control points. The deformations on the map were caused by wrong decisions of surveyors without verification of the points used.

Locations no. 1 and no. 2 were evaluated as homogenous. The location no. 3 as a whole could not be considered homogenous. However, if we compare the values of size and direction of positional deviations between location no. 1 and location no. 2, we can see that their values differ a lot (Fig. 7).

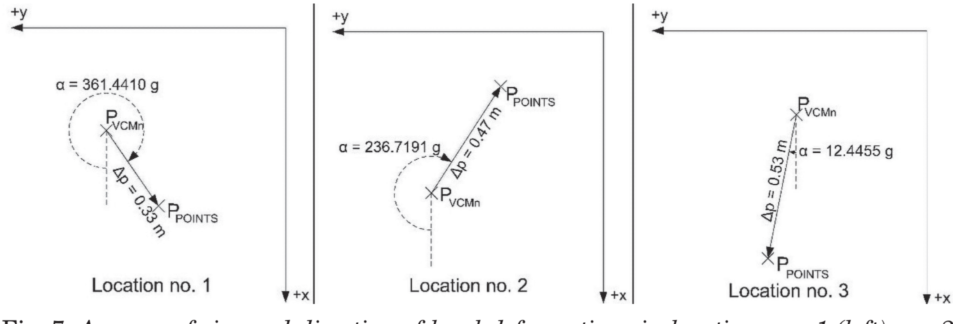

Fig. 7. *Average of size and direction of local deformations in locations no. 1 (left), no. 2 (centre) and no. 3 (right).*

4.4. The solutions for renewal of VCMn in Hlohovec

In general, the renewal of VCMn is possible if:

A. vector geodetic designs which are created only during updating of the VCMn sufficiently cover the cadastral unit,

B. it is possible to distinct locations without deformations, locations with homogeneous deformations and locations with inhomogeneous deformations and at the same time the borders of the locations with particular local deformation are visibly defined.

If these conditions are fulfilled, the methods of renewal of VCMn are:
- part of the map where the local deformations could be considered homogeneous would be transformed to a correct position, the objects in the POINTS layer would be used for the transformation,
- locations with inhomogeneous local deformations on the map would be remapped.

Under ideal conditions, the renewed map would be created by connecting the transformed, remapped and original locations. However, this is very rare in practice. For each cadastral unit specific practice has to be used (Hudecová et al. 2016). The biggest problem is the low coverage of cadastral unit with vector geodetic designs. Nowadays the objects in the POINTS layer are created only during updating of the VCMn, so there is a low probability that this layer would include enough points for the correction of the VCMn in the near future. The information about the positional deviations in detailed points have to be obtained in some other way. There are several possibilities:
- addition of terrestrial measurements to the vector geodetic designs in chosen points in case of small area,
- addition of measurements using modern measuring technologies, such as RPAS photogrammetry, to the vector geodetic designs in case of bigger area,
- using some other existing maps with satisfying precision.

Renewal of VCMn in Hlohovec:

The situation is characterized by unsatisfying positional precision of the network of control points which caused local deformations of varying sizes and directions (Fig. 7). In the present, there are approximately 18,500 objects in the VCMn, vector geodetic designs covers approximately 10% and only 150 of them are in the POINTS layer (approximately 1%).

Considering the available documentation, 2 homogenous and 1 heterogeneous locations were identified. Size and direction of local deformations differ if we compare them with each other. The borders of identified locations could not be determined visibly. We can state that the coverage of cadastral unit with vector geodetic designs is not sufficient (Fig. 2) and the map does not meet the conditions for the renewal A and B. New measurements should be added to the existing vector geodetic designs using modern measuring technologies, mainly RPAS photogrammetry. The measurements have to provide the identifications of all the locations with homogenous and inhomogeneous deformations together with their borders.

5. Conclusions

VCMns in Slovakia can include local deformations (chap. 2). There are several reasons for their presence (chap. 4.3). This is indicated by the existence of the POINTS layer (chap. 2.3). VCMns with disrupted homogeneity makes about 10% of all the maps. The main problem is that there will not be any cadastral mapping within the next few years because of financial reasons. In the article, general principles of methodology of testing the homogeneity of the VCMn (chap. 3.2) and principles for renewal of VCMn (chap. 4.1) were proposed. Introduced solutions should minimalize the time and costs of the correction and the results should be reliable at the same time. All the results of the previous measurements in the vector geodetic designs should be used effectively to the greatest extent possible. The methods of measurement are proposed depending on the extent of mapped area for cases when it is necessary to add new measurements to the existing vector geodetic designs.

In tested cadastral unit of Hlohovec, the reasons for the presence of local deformations were analysed and explained (chap. 4.2 and 4.3). The use of the network of control points with unsatisfying positional precision caused several local deformations of varying size and direction. For the purposes of the analysis, two locations in the urban area and one location in the rural area were chosen (Fig. 2). The coverage of the cadastral unit with the vector geodetic designs was evaluated as unsatisfying and it was recommended to add some new measurements using mainly modern measuring technologies, such as RPAS photogrammetry (chap. 4.4).

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Analiza numeričke homogenosti katastarskih planova u vektorskom obliku

SAŽETAK. U katastru nekretnina u Slovačkoj postoji niz podataka različitog porijekla kao i različite kvalitete. Jedan od glavnih problema je kvaliteta katastarskih planova. Više od pola tih planova ne udovoljava današnjim zahtjevima evidentiranja nekretnina te ih je potrebno obnoviti. Ovaj se rad bavi analizom homogenosti, koja je prvi korak u obnavljanju numeričkoga katastarskog plana u vektorskom obliku. Numerički katastarski plan trebao bi biti najbolji jer je sastavljen od koordinata koje su rezultat numeričkog mjerenja, no na nekima od njih postoje različite lokalne deformacije. Na lokacijama s deformacijama postoje objekti u sloju POINTS gdje su pohranjene koordinate točaka određene GNSS-om. Prvi korak u obnavljanju tih planova je analiza homogenosti. Taj je korak vrlo važan jer je potrebno razumjeti kako se ponašaju lokalne deformacije u cijeloj katastarskoj jedinici te u kojim je dijelovima potrebna obnova. Analiza se sastoji u razmatranju broja objekata u sloju POINTS, izboru lokacija s lokalnim deformacijama, izračunavanju veličine i smjera lokalnih deformacija u odabranim točkama te u međusobnoj usporedbi lokacija. Analiza homogenosti dovodi do specifičnih metoda za obnovu numeričkoga katastarskog plana. To je rješenje za sljedeći korak obnove specifično za svaku katastarsku jedinicu.

Ključne riječi: *katastarski planovi u vektorskom obliku, lokalne deformacije, transformacija, homogenost plana, parametri kvalitete plana, terenska mjerenja.*

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