ATTRIBUTE 'MEAN ERROR OF THE BOUNDARY POINT POSITION' IN THE ASPECT OF ACCURACY ASSESSMENT OF PARCEL SURFACE AREA

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Abstract

Standardized values of boundary points' attributes add up to useful element in the scope of land properties features description. Assumedly, these attributes should, inter alia, make an accuracy assessment of parcel's surface area analytical determination possible. One of the boundary point attributes is mean error of the boundary point position in reference to the first-order geodetic control (the Polish acronym: BPP). This attribute has six possible values, complying with specific intervals of boundary point position accuracy. Taking into account, that according to the polish legal regulations concerning real estate cadastre, the surface area of parcel may be determined on the basis of boundary points coordinates included in numerical description of boundaries, the primary factor affecting the accuracy of analytical determination of parcel's surface area is the mean error of the boundary point position. The capabilities of standardized values for boundary point attributes used for parcel's surface area accuracy assessment were analyzed in the article. The constraints of such an approach were outlined in this work as well. Analyses were concurred by empirical examples. Finally, basing on the results of control surveying activities, the BPP attribute usefulness assessment for parcel's surface area mean error estimation was carried out.

Keywords: real estate cadastre, cadastral parcel, boundary, boundary point, surface area, evaluation

Introduction

The Register of land and buildings, referred to as the real estate cadastre, is a collection of data on parcels, buildings and premises. Under the provisions of the Geodetic and Cartographic Law (Act 1989), this data is used e.g. for the purposes of tax and consideration assessment, spatial and economic planning, or real property denotation in land and mortgage registers, which are a record of the legal status of real estate. The cadastral parcel is considered to be the leading object of the cadastre (HANUS et al., 2013). Its boundaries, defining the extent of property rights, are the most important of the spatial attributes of the parcel. The surface area of the parcel, which is a metric measure defining the size of a specific object, is a derivative of its boundaries. Due to its extensive use, data on the surface areas of the parcels should be of adequate accuracy and reliability (BENDUCH, 2017).

The data on the surface areas of the parcels have been obtained by various methods. Initially, the results of the surveys, carried out on the existing cartographic materials, formed the basis for the data capture (FROLOV, MALING, 1969). The two approaches which could be distinguished here are the graphical and mechanical methods. The surface areas which had been captured in this way, were burdened with errors resulting from the application of the then surveying techniques, delineation of boundary lines on the map, as well as from the deteriorating quality of the cartographic materials (HANUS, 2006). For this reason, the analytical method for determining surface areas of parcels is currently the most popular one (SHIH, 1995; PĘDZICH, KUŹMA, 2012). This method is based on the coordinates of turn points of parcel boundaries in accordance with the algorithms proposed by Carl Friedrich Gauss.

So far, numerous research studies have been performed regarding the broadly defined accuracy and reliability of surface areas of parcels, and they have been described in literature (GHILANI, 2000; HEJMANOWSKA et al., 2005; DESKA, 2006; ALKAN, SOLAK, 2010; DOSKOCZ, 2011; KWINTA, 2012; DOSKOCZ, 2014; HANUS et al., 2014; BENDUCH, 2016a; MIKA, LEŃ, 2016; BAJTALA et al., 2017; BERK, FERLAN, 2018). A number of publications on the use of remote sensing and photogrammetry for the purpose of determining surface

areas of parcels have been reported (PLUTO-KOSSAKOWSKA et al., 2007; PLUTO-KOSSAKOWSKA et al., 2008; NOWAK DA COSTA, WALCZYNSKA, 2010; OLOFSSON et al., 2014; ZHAO, PEI, 2016). The Authors analyzed the way in which the mean errors of the surface areas of the parcels propagate to the final result of valuation of land properties (BENDUCH, 2016b). The influence of changes in surface areas of parcels on land taxation was also assessed. These changes resulted from the need to adapt the cadastral data to the applicable technical requirements (BENDUCH, PĘSKA, 2016). The mean errors of boundary points (PREWEDA, JASIŃSKA, 2014; BENDUCH, PĘSKA-SIWIK, 2017) as well as the accuracy of boundary lines of parcels (HANUS, 2013) were analyzed as key factors for the correct determination of their surface areas (OGECHI, ODERA, 2015; HANUS et al., 2018). In the research studies carried out in Poland, the attribute of the boundary point which is the most frequently referred to, is: "The mean error of boundary point location in relation to the 1st-order geodetic control network". So far, however, no analyzes have been carried out to assess the suitability of this attribute for estimating the accuracy of surface areas of parcels included in the real estate cadastre. The authors of this research paper undertook this task. The theoretical considerations were complemented by the results of empirical tests performed on the selected objects.

Boundary Point Location Error Attribute (Polish abbreviation: BPP)

Recent changes introduced into the real estate cadastre in Poland have contributed to the increased amount of data collected in this public register (PIETRZAK et al., 2012). It has become necessary to record selected attributes of individual objects in a standardized form (MIKA, 2017; BIELECKA, ZWIROWICZ-RUTKOWSKA, 2013). This also applies to the accuracy of determining the location of a boundary point. This information is currently entered using the boundary point attribute: Boundary Point Location Error [BPP]. In the Land Administration Domain Model [LADM], the *estimatedAccuracy* attribute for the *LA_Point* class is the equivalent of this attribute (ISO, 2012). The current list of permissible values of the BPP attribute with the corresponding definitions is demonstrated in Table 1.

Table 1. Permissible values of Boundary Point Location Error [BPP] attribute and their definitions.

BPP	Mean error relative to first-order geodetic control [m]
1	0.00 – 0.10
2	0.11 – 0.30
3	0.31 – 0.60
4	0.61 – 1.50
5	1.51 – 3.00
6	> 3.00

Source: Own study based on (REGULATION, 2001).

An important problem is the lack of uniform rules for determining the value of the mean error of boundary point location relative to the first-order geodetic control when using various, legally acceptable, surveying techniques, especially photogrammetric methods which are becoming increasingly popular. The BPP is usually attributed subject to the type of actions which are aimed at determining the location of boundary points. Accuracy assessment is usually not carried out. In other words, the value of the BPP attribute is strongly correlated with the source of the data on the boundary point location. It was pointed out in the literature that the values of the BPP attribute entered into the modernized cadastre are frequently inconsistent with the actual status (BENDUCH, PĘSKA-SIWIK, 2017). This issue is of key importance in the context of using this attribute for the purpose of assessing the accuracy of surface areas of parcels.

Surface area of the parcel in the real estate cadastre

Pursuant to §62 section 1 of the Regulation on the register of lands and buildings (REGULATION, 2001), the surface area of the parcel, constituting one of its spatial attributes, is determined using the rectangular coordinates of boundary points included in the numerical description of boundaries. Under this provision, a necessary condition to determine the surface area using the analytical method is to define the location of all boundary points of the parcel with a mean error not greater than 0.30 m relative to the first-order geodetic control, which corresponds to the value of the BPP attribute equal to 1 or 2. Otherwise, the surface areas of the parcels previously entered into the register of land and buildings remain valid. Therefore, in many regions of Poland, there is a lack of uniformity in the methods used for calculating surface areas of parcels. Consequently, in addition to the varying levels of accuracy and reliability, the cadastral data describing surface areas of parcels is recorded with unequal precision. Pursuant to the regulations that are no longer in force (ORDINANCE, 1969), surface areas of parcels located outside cities and

housing estates were additionally rounded to one are. Currently, the surface area of any parcel should be expressed in hectares with the accuracy of one square meter, regardless of the circumstances.

Therefore, it may be presumed that the procedure for estimating the accuracy of surface areas of parcels using the values of the BPP attribute registered in the cadastre can not be carried out for all objects in a given area. If any of boundary points of the parcel are characterized by the BPP attribute with a value greater than or equal to 3, then there are no grounds for calculating the surface area by the analytical method. Nevertheless, according to the Authors of this research paper, even in such a situation, determining the mean error of the surface area in the manner provided for analytical calculations (Formula 3) should be a good approximation of the actual level of accuracy of these data. It is worth reminding that the surface area of the parcel, regardless of the method used for its determination, is always the resultant attribute of the parcel boundaries (HYCNER, HANUS, 2007). Currently, neither the database of the real estate cadastre nor the reports generated from this database contain information on the accuracy with which the surface area of the parcel was determined. Such information could be a valuable clue both for landowners and potential buyers, as well as public administration bodies, including tax authorities.

Assessment of accuracy of the surface area of the parcel

In order to calculate the surface area of the parcel by the analytical method, the following Formulas (which can be used interchangeably) are used:

$$2S = \sum_{i=1}^{n} X_i \cdot \left(Y_{i+1} - Y_{i-1} \right) \tag{1}$$

$$-2S = \sum_{i=1}^{n} Y_i \cdot \left(X_{i+1} - X_{i-1} \right) \tag{2}$$

where: S – the surface area of the parcel; n – the number of parcel boundary points; X_i, Y_i – the coordinates of the i-th parcel boundary point.

Basing on the Gaussian law of propagation of mean errors and carrying out the transformations of Formula 1 or Formula 2, it is possible to derive the correct formula for the estimation of the mean error of the surface area of the parcel:

$$m_S = \sqrt{\frac{1}{8} \cdot \sum_{i=1}^{n} m_{p_i}^2 \cdot \left[\left(Y_{i+1} - Y_{i-1} \right)^2 + \left(X_{i-1} - X_{i+1} \right)^2 \right]} \tag{3}$$

where: m_S – the mean error of the analytical determination of the surface area; m_{pi} – the mean error of the position of the i-th parcel boundary point; n – the number of parcel boundary points; X_i, Y_i – the coordinates of the i-th parcel boundary point.

Implementation of Formula 3 requires the knowledge of errors of the location of all boundary points of the parcel. It sometimes happens that this Formula is subject to additional simplification by adopting the same location error for all boundary points of the parcel. Such simplification, as discussed e.g. in (HANUS, 2006; BENDUCH, 2016a), may eventually lead to results that will be significantly divergent from those obtained in the direct implementation of Formula 3. This may occur when boundary points of the parcel are characterized by a large diversity as regards the accuracy which their location has been determined with.

While analyzing Formula 3, it can be concluded that the accuracy of determining the surface area of the parcel is influenced by the three basic factors: errors of boundary point location, distribution of these points and their number. However, regardless of the geometry of the parcel, if errors of the boundary point location tend to zero, the mean error of the surface area of the parcel also tends to zero. A similar situation will occur if the number of boundary points is increased, although the function of the mean error of the parcel surface area will then tend to zero at a significantly slower pace, especially when the boundary points are located close to each other - unevenly. The most significant factor when determining the surface area of the parcel are therefore boundary point location errors.

BPP attribute and accuracy of the parcel surface area

In the real estate cadastre in Poland, the information about boundary point location errors is conveyed through the values of the BPP attribute, which correspond to the intervals demonstrated in Table 1. Therefore, to estimate the mean error of the surface area of the parcel, it is the most reasonable to take the maximum possible value of the boundary point location error for the specified value of the BPP attribute, which, to some extent, protects against making a second-order statistical error (the so-called *false negative*) in the inference. If BPP=6, theoretically, any value greater than 3.00 m can be adopted. For the calculations to be unified, it is reasonable to use the same, predetermined value of the boundary point location error. The value for BPP=6 recommended by the Authors of this research paper is 4.65 m, which results from the interpolation carried out with the quartic polynomial. It should be emphasized that the BPP=6 attribute occurs sporadically. Its entering into the database of the real estate cadastre requires the consent of the Surveyor General of Poland. For the analyzed research objects, no such cases were identified.

It should be noted that using the boundary point location error and Formula 3, it is only possible to determine the confidence interval which the surface area is located within at a given probability level. Due to the lack of data on the direction and sense of the vector of individual boundary point location errors, it is impossible to determine what the actual influence of this factor on the accuracy of determining the surface area will be. It is only possible after a control survey of the boundary points for which there is a reasonable presumption that their location is in conformance with the legal status of the land. Then, it is also possible to compare the record surface area [S_{EWID}], entered into the database of the real estate cadastre, with the geodetic surface area [S_{GEOD}] obtained as a result of the performed surveys.

Figure 1 illustrates the basic variants of the influence of the boundary point location errors on the surface area of the parcel. It is important to note that even if there are large values of the BPP attribute, the surface area of the parcel may eventually turn out to be determined correctly, i.e. in a way that is consistent with the actual status [Variant C].

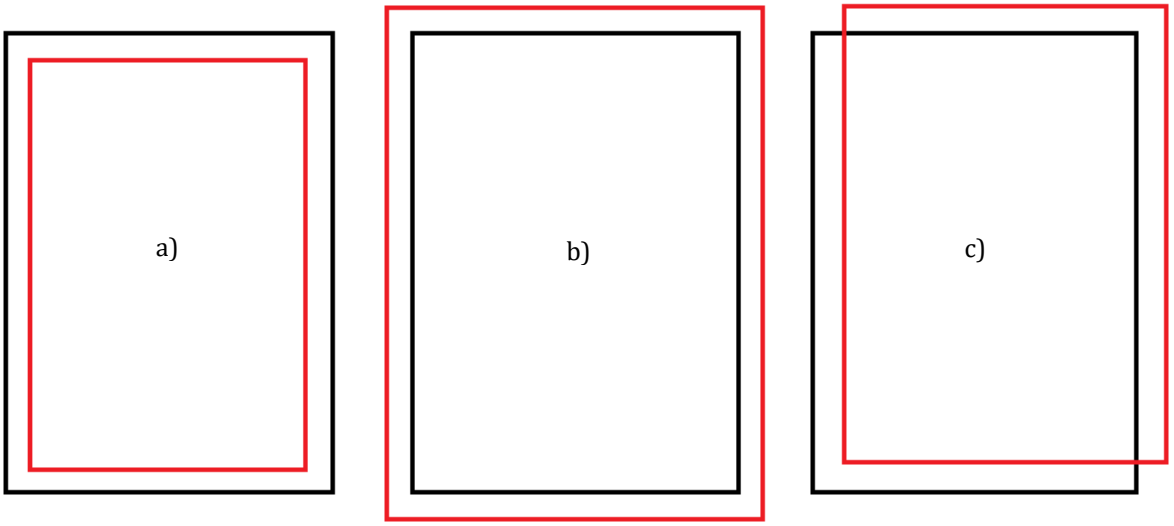

Fig. 1. Possible influence of boundary point location errors on parcel surface area:
a) [$S_{EWID} > S_{GEOD}$]; b) [$S_{EWID} < S_{GEOD}$]; c) [$S_{EWID} = S_{GEOD}$].
Source: Own study.

Nevertheless, the assessment of the accuracy of surface areas of the parcels entered into the real estate cadastre based on the BPP attributes seems to be a solution that allows to obtain relevant information about the uncertainty of the parcel surface area in the comprehensive and automated manner. However, it is necessary to ensure an appropriate level of reliability of the BPP attribute values declared by the contractors.

Research methodology and description of test objects

In order to assess the suitability of the BPP attribute for estimating the accuracy of surface areas of the parcels entered into the real estate cadastre, a control survey was performed using the GNSS RTN method, which covered 80 test objects - cadastral parcels located in three different cadastral districts in southern Poland, where works related to the modernization of the registers of land and buildings have been carried out in recent years. The survey included a total of 440 boundary points identifiable directly in the

field, for which there was a reasonable presumption that their location was in conformance with the legal status of the land. In the case of urban parcels, these were most often corners of fences, and in the case of agricultural parcels – boundary strips and the so-called tripoints. Basic information about the research objects is illustrated in Figure 2.

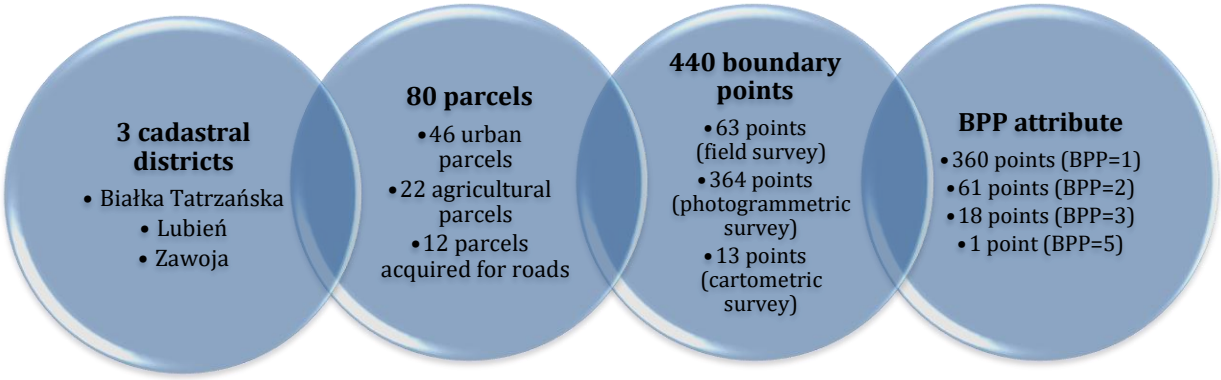

Fig. 2. Research objects in numbers - graphic presentation.
Source: Own study.

The number of boundary points for the analyzed parcels ranged from 3 to 23. Only in the case of several agricultural parcels in Lubień cadastral district, the same boundary points were used in the calculations more than once. According to Figure 2, the spatial data on the location of most of the controlled boundary points were captured using photogrammetric techniques. The least (only 13) boundary points were recorded in the cadastre after the performance of cartometric surveys. 421 of the surveyed boundary points, which accounted for almost 96% of the sample size, were included in the numerical description of the boundaries (BPP=1 or BPP=2). This means that the accuracy of the location of these boundary points declared by the contractors of the surveying works allowed to use their coordinates for the calculation of the surface areas of the parcels by the analytical method.

The results of the GNSS RTN control surveys were compared with the corresponding coordinates of the boundary points entered into the real estate cadastre. The linear deviation dL was obtained, which was calculated from the following Formula:

$$dL_i = \sqrt{(X_{pi} - X_{ei})^2 + (Y_{pi} - Y_{ei})^2} \tag{4}$$

where: dL_i – linear deviation at the i-th control point; X_{pi}, Y_{pi} – coordinates of the i-th boundary point, captured during the performed GNSS RTN surveys; X_{ei}, Y_{ei} – coordinates of the i-th boundary point, entered into the modernized real estate cadastre.

According to Formula 4, the coordinates of boundary points captured from control surveys [X_{pi}, Y_{pi}] were treated as error-free values. However, the spatial data contained in the real estate cadastre regarding the location of boundary points [X_{ei}, Y_{ei}] and the values of the BPP attribute assigned to these points were subject to verification. Then, based on the coordinates of the control points [X_{pi}, Y_{pi}], using Formulas 1 and 2, the geodetic surface area [S_{GEOD}] of the analyzed parcels was determined. The results were confronted with the corresponding surface areas [S_{EWID}], entered into the cadastral database. The mean errors of the surface areas of individual parcels estimated in accordance with Formula 3 were compared using the declared values of the BPP attribute and the linear deviations dL. It was verified whether the calculated geodetic surface areas [S_{GEOD}] fell within the constructed confidence intervals for the surface areas entered into the cadastre [S_{EWID}] at the probability levels of 68%, 95% and 99%. The results of the research were presented in the analytical and graphical forms.

Research results

Table 2 demonstrates the basic statistics on the results of field surveys carried out by the GNSS RTN method at controlled boundary points.

The obtained average value of the linear deviation dL_i at the level of 0.43 m, calculated for 440 control points was 2.8 times higher than the mean value of the error of the analyzed boundary point

locations, estimated based on the BPP attributes entered into the cadastre. The same situation occured in the case of standard deviation. This proved a significantly greater differentiation in the accuracy of the location of individual boundary points in relation to the information declared in the real estate cadastre after the modernization. The minimum and the maximum values of the linear deviation dL_i and of the mean error of the boundary point location declared through the BPP attribute, relative to the first-order geodetic control, were similar to each other.

Table 2. Basic statistics for control points.

Description	Linear deviation dL_i [m]	Mean error according to BPP attribute [m]
Average value	0.43	0.15
Standard deviation	0.52	0.18
Minimum value	0.01	0.10
Maximum value	3.55	3.00

Source: Own study.

The values of the dL_i linear deviations at the control points were also analyzed depending on the source of capture of the data on the boundary point location (ZRD attribute).

Table 3. Average value of linear deviation dL_i and boundary point location error according to BPP attribute depending on source of capture of data on boundary point location (ZRD attribute).

ZRD	Definition	Number of control points	Average value of linear deviation dL_i [m]	Average value of mean error according to BPP attribute [m]
1	Land surveys preceded by property delimitation, restoration of boundary markers, determination of boundary points or determination of their location in a different mode, including the one specified in §39 sections 1 and 2 of the regulation (REGULATION, 2001)	53	0.24	0.25
3	Photogrammetric surveys of boundary points, the location of which has been previously determined under §37 section 2 (REGULATION, 2001), as well as photogrammetric surveys of boundary markers depicted in aerial photographs or on the orthophotomap as a result of their labelling before taking pictures	348	0.43	0.11
5	Approved projects of land subdivision or consolidation and subdivision.	10	0.24	0.26
8	Screen vectorization of the raster map without the use of field survey results	13	1.11	0.60
9	Data sources other than ZRD1 - ZRD8, including the results of findings and analyses referred to in §39 section 3 (REGULATION, 2001)	16	0.63	0.46

Source: Own study based on (REGULATION, 2001).

It follows from Table 3 that the biggest discrepancies were obtained for the boundary points whose location was determined during the modernization using photogrammetric methods (ZRD=3 and ZRD=9). For photogrammetric surveys preceded by the determination of boundaries (ZRD=3), the average value of the linear deviation dL_i turned out to be 4 times greater than the average value of the mean boundary point location error according to the declared BPP attribute, and in the case of cartometric surveys on the ortophotomap (ZRD=9 for the studied area) it was 1.4 times higher, respectively. Also for the boundary points, whose location was determined using the screen vectorization of the raster cadastral map (ZRD=8), there were significant discrepancies in this respect. Therefore, it can be concluded that the values of the BPP attribute of the boundary points declared by the contractors of geodetic works proved to be too low in the considered cases. It is worth noting that for 343 out of 348 analyzed boundary points whose location during the modernization was determined using photogrammetric surveys preceded by the determination of the boundaries (ZRD=3), the BPP=1 attribute was assigned. This was also the case in agricultural areas, where the possibilities of identifying the course of the parcel boundary are very limited. For geodetic field surveys preceded by the determination of boundaries (ZRD=1), as it was in the case of approved real estate subdivision projects (ZRD=5), a good consistency was obtained between the results of control surveys and the data entered into the real estate cadastre.

Because the mean linear deviation dL_i at the level of 0.43 m, contained in Table 2, exceeds the value of the mean boundary point location error which is permissible for the numerical description of the boundaries (0.30 m), it can be assumed that the analyzed sample contains a significant percentage of boundary points whose use for the analytical calculation of the parcel surface area should not occur. This is confirmed by the results presented in Table 4.

Table 4. Percentage of boundary points meeting the requirements of the numerical description of boundaries.

Description	Percentage
BPP ≤ 0.30 m	95.7%
dLi < 0.30 m	60.7%
dLi < 0.40 m	70.2%

Source: Own study.

The linear deviation dL_i, treated as true value of the boundary point location error in relation to the first-order geodetic control, is less than 0.30 m for 60.7% of the analyzed control points. Assuming an additional adjustment of 0.10 m due to the identification of boundary points directly in the field during control surveys, this percentage increases to 70.2%. However, this value is still distant from the one obtained from the analysis of the BPP attributes of the considered boundary points. The difference of 35 and 25 percentage points corresponds to 154 and 112 boundary points, respectively, which according to the adopted research methodology should not be used for the analytical calculation of surface areas of the parcel, contrary to the information contained in the cadastre.

This proves the average level of reliability of the declared values of the BPP attribute. In case of merely 101 control points, the obtained value of the linear deviation dL_i was found to be consistent with the value of the BPP attribute assigned to a given boundary point ($dL_i \leq$ BPP), which accounted for 23.0% of the sample. Taking into account the aforementioned adjustment for the identification at the level of 0.10 m, this percentage increases to 46.8%. This is not a satisfactory value, though.

In view of the above, it can be assumed that the mean errors of the surface areas of the parcels determined using the BPP attributes of boundary points contained in the real estate cadastre will be underestimated. The calculations, the results of which are contained in Table 5 and Figure 3, confirm this thesis.

Table 5. Basic error statistics of mean surface areas of parcels calculated according to dL_i and BPP.

Description	Calculations according to dL_i	Calculations according to BPP	Difference
Average value of mean error of surface area of parcel [m²]	32.30	9.03	23.27
Average value of relative error of surface area of parcel	3.5%	0.9%	2.6%

Source: Own study.

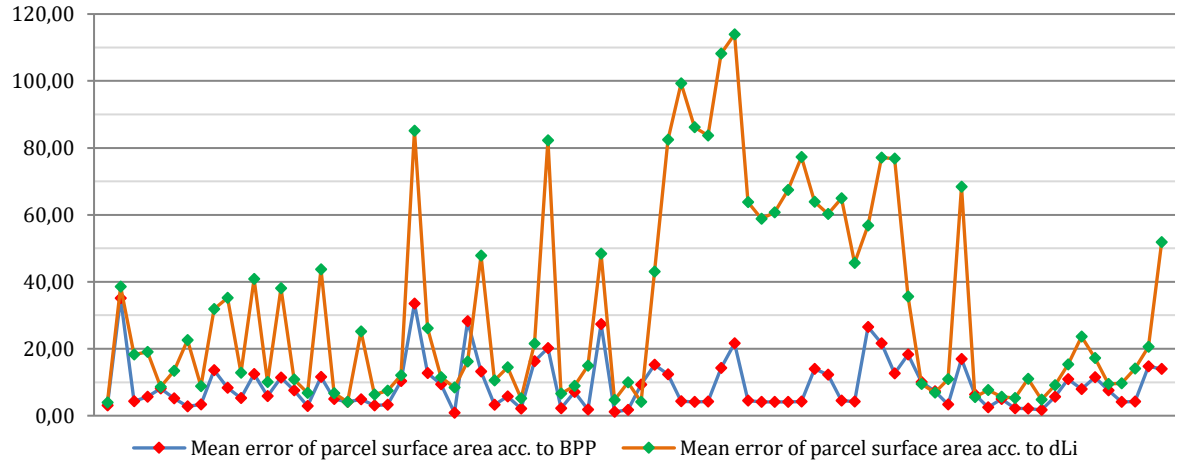

Fig. 3. Comparison of mean errors of surface areas of test objects [m²] calculated according to BPP and dL_i.
Source: Own study.

The mean errors of the surface areas of the analyzed parcels, estimated using Formula 3 and linear deviations dL_i, turned out to be greater in 75 out of 80 considered cases, which accounted for 93.8% of the sample. According to the information contained in Table 5, the average value of the mean error of the surface area was almost four times higher for the calculations performed using the linear deviations dL_i of the control points than for the calculations taking into account the value of the BPP attribute. An analogous situation occurs with regard to relative errors of surface areas. The largest discrepancies were noted for agricultural parcels, which is illustrated in the middle part of Figure 3. The maximum difference between the mean error of the surface area according to dL_i and BPP was 95.03 m^2. For a relative error, these were as many as 24 percentage points. These discrepancies relate to other objects.

Then, the surface areas of the test objects were compared, based on the results of control surveys [S_{GEOD}], with their surface areas entered into the real estate cadastre [S_{EWID}]. The results were presented in the analytical form (Table 6) and graphical form (Fig. 4).

Table 6. Basic statistics on the comparison of surface areas of parcels.

Description	Result
Average value of difference modulus [S_{GEOD}] - [S_{EWID}] [m^2]	30.37
Average percentage share of difference modulus [S_{GEOD}] - [S_{EWID}] in [S_{EWID}]	3.4%

Source: Own study.

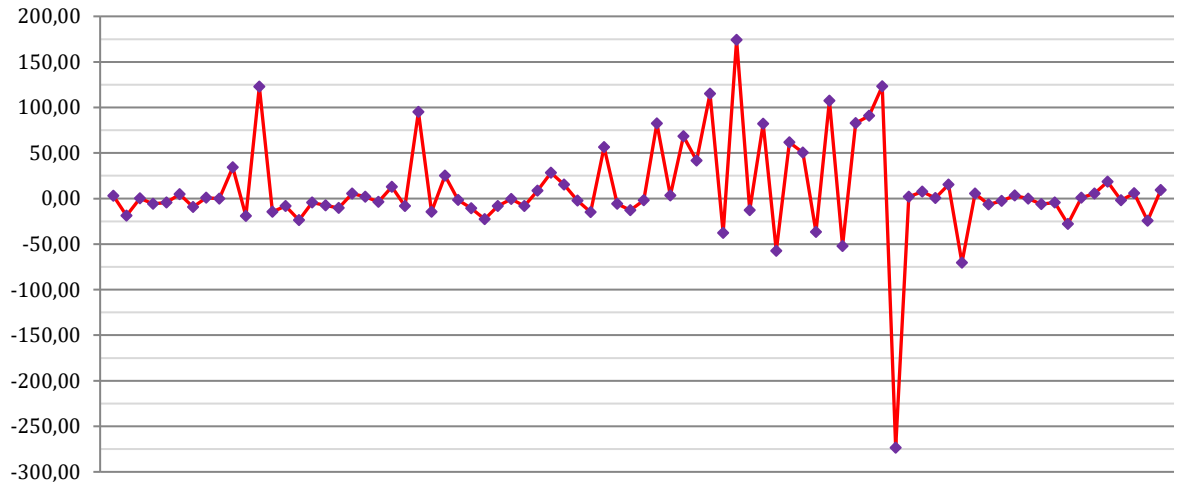

Fig. 4. Differences [S_{GEOD}] - [S_{EWID}] of analyzed test objects [m^2].
Source: Own study.

It is worth noting in the first place, that the test results contained in Table 6 almost coincide with the average value of the mean error and the relative error of the surface areas of the parcels estimated based on the linear deviation dL_i (Table 5). They deviate from the average value of these errors obtained for the calculations taking into account the BPP attribute. It can be assumed therefrom that the mean errors of the surface areas of the parcels calculated with the use of linear deviations dL_i of individual control points are more reliable.

In the case of 40 test objects, it was found that the surface area determined as a result of the control surveys [S_{GEOD}] was greater than the surface area in the real estate cadastre [S_{EWID}], which accounted for exactly 50% of the sample. Therefore, there is no basis for the hypothesis that the survey results would be subject to a systematic error. The total geodetic area [S_{GEOD}] of the test objects turned out to be 718 m^2 larger than the cadastral area [S_{EWID}]. For 37 test objects, the difference between [S_{GEOD}] and [S_{EWID}] did not exceed 1%, and in the case of 8 objects, it did not exceed 0.1%. Thus, individual cases were identified where, despite significant linear deviations dL_i at the controlled boundary points, the geodetic surface area [S_{GEOD}] turned out to be consistent with the cadastral area [S_{EWID}]. This possibility was suggested in Fig. 1.

The percentage of test objects was also verified, where the difference between the surface areas calculated after the performance of the control survey [S_{GEOD}] and the surface area entered into the real estate cadastre [S_{EWID}], did not exceed the estimated value of the error of the mean surface area.

The results presented in Table 7 demonstrate that only in 35.0% of the analyzed cases, the mean error of the surface area determined using the BPP attribute was found to be less than or equal to the difference between [S_{GEOD}] and [S_{EWID}]. Better calculation results were ensured by using the linear deviations dL_i. This is yet another proof that the mean errors of the surface areas of the parcels located in the analyzed study area, determined using the values of the BPP attribute of the boundary points, may be underestimated.

Table 7. Number and percentage of analyzed parcels where the difference [S_{GEOD}] - [S_{EWID}] is less than or equal to the estimated value of mean error of surface area.

Description	Number of parcels	Percentage
[S_{GEOD}] - [S_{EWID}] < Mean error of surface area acc. to BPP	28	35.0%
[S_{GEOD}] - [S_{EWID}] < Mean error of surface area acc. to dL_i	50	62.5%
Difference	22	27.5%

Source: Own study.

Finally, it was verified whether the calculated geodetic surface areas [S_{GEOD}] were within the constructed confidence intervals for surface areas of the parcels entered into the cadastral database [S_{EWID}] at the probability level of 68%, 95% and 99%.

Table 8. Number and percentage of test objects whose [S_{GEOD}] falls within the confidence interval for [S_{EWID}].

Description	Calculations based on linear deviations dL_i		Calculations based on value of BPP attribute	
	Number of objects	Percentage	Number of objects	Percentage
P = 68%	50	62.5%	28	35.0%
P = 95%	75	93.8%	39	48.8%
P = 99%	78	97.5%	51	63.8%

Source: Own study.

The performed analysis confirmed that according to the research methodology adopted for the sample of 80 objects, the mean errors of the surface areas of the parcels calculated based on the BPP attribute of boundary points were too low. At the probability level of 95%, the geodetic surface area [S_{GEOD}] of 41 test objects did not fall within the confidence interval constructed for the cadastral surface area [S_{EWID}]. Having increased the probability level to 99%, that was the case for 29 studied objects. This means that the information on the mean errors of the surface areas of the parcels determined based on the values of the BPP attribute assigned to boundary points, which would be entered into the cadastral database, could lead to erroneous conclusions. The level of reliability of this information would be unsatisfactory for the specified cases.

Conclusions

The performed research studies allowed to formulate the following conclusions:

- The main factor influencing the mean error of the surface area of the parcel is the accuracy which the location of the boundary points was determined with.
- Currently, the information on the estimated accuracy of surface areas of parcels is not entered into the real estate cadastre in Poland. In theory, the introduction of such an attribute could contribute e.g. to the improved protection of property rights of the parties being part of real estate transactions. It would also be a step towards ensuring that the subject data contained in the database of the real estate cadastre was under warranty. However, the attribute determining the mean error of the surface area of the parcel would have to be legally approved beforehand, by amending relevant provisions.
- A comprehensive assessment of the accuracy of surface areas of parcels can be carried out thanks to the values of the BPP attribute of boundary points entered into the cadastre. This also applies to surface areas that have been determined by a method other than the analytical method. In calculations, for the specified value of the BPP attribute, it is recommended to adopt the maximum possible value of the boundary point location error in relation to the first-order geodetic control.
- The reliability of the mean errors of the surface areas of the parcels estimated using the BPP attribute is strongly dependent on a reliable assignment of the appropriate values of this attribute to the individual boundary points. The research studies revealed numerous cases where the mean errors of the surface areas of the parcels were proven to have been underestimated due to the incompatibility

of the value of the BPP attribute declared by the contractors with the actual state, especially in the case of the data on the location of boundary points captured using photogrammetric methods and cartometric surveys.

- As regards the estimation of the mean errors of the surface areas of the parcels, significantly more reliable results were obtained when using the values of the linear deviations dL_i identified at the controlled boundary points. This approach also allows for a series of additional analyzes related to the quality of the recorded data describing surface areas. However, it is more time-consuming and requires higher expenditures.
- In view of the above, there is a need to specify uniform rules for assigning individual values of the BPP attribute to specific boundary points. Only then this attribute could be fully used for the analyzes related to the estimation of the mean error of the surface areas of the parcels without the need for additional verification.

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