Demarcation Technique and Geometric Analysis of Village Boundaries Resulting from Delineation of Land Areas (*ujazd*) in the Middle Ages in the Wielkopolska Region (Poland)

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Abstract: The paper presents the genesis of village borders' shape formed in the Middle Ages and presents rules according to which demarcations were made. The hypothesis that the borders formed in the Middle Ages had a shape similar to a circle or segment of a circle was accepted. This hypothesis was confirmed by geometric analysis of borders from that period. Geometric elements of the boundaries were calculated: types of arcs, their radii, lengths and central angles. The center of the newly granted area was analyzed, as this location played a major role in the delineation of the boundary. Accuracy of measurements was determined and influence of errors on the presented results was analyzed. Wielkopolska was chosen as the research area because natural conditions had no influence on the shape of the borders. The starting materials were topographic maps in the scale of 1:25,000 (Messtischblätter) from the years 1887–1890. The research confirmed the hypothesis of a circular shape of borders formed in the Middle Ages in the studied area. In the original allocations, the area took the shape of a circle, which was a specific pattern for the villages to be founded. Later, as the settlement developed, the villages took on the shapes of circle segments. Considering the demarcation technique, the accuracy of the boundary staking was high. The deviation from a perfect circle did not exceed approximately ± 60 m, and the length of the arc radius varied between 1500 and 2200 m. The historical village boundaries from medieval times, preserved to this day in their residual form, have a historic character due to their antiquity and should be protected.

Keywords: geometric analysis; the shape of boundaries; demarcation

1. Introduction

Spatial arrangements, of historical rural landscape, are an important element of cultural heritage [1–5]. Spatial layout is a mixture of anthropogenic elements, e.g., field layout, settlements, transport routes and natural elements, e.g., water, forests, meadows. In the literature we can find works analyzing rural historical landscape created and transformed in different centuries of our history. Considerations on the definition of rural landscape [6,7], its types [8], methods of its reconstruction [9,10], analysis of individual anthropogenic elements [11–13] as well as natural elements [14–16] bring the reader closer to understanding how rural landscape was formed and transformed.

Studies on landscape reconstruction are based on descriptive and cartographic materials [17] or luminescence profiling [18] as well as, when the study area is smaller [1], field studies [19]. The use of cartographic materials should be preceded by an analysis–verification–for which research they can be used in order to take into account uncertainties resulting from the limitations of these materials [20]. The various medieval field systems–open fields, metes and bounds and the rectangular system [21–25] were the beginnings of spatial planning [26] shaping the rural landscape.

Landscape metrics are often used in landscape studies to show geometric relationships [27,28]. They are also used to determine the geometric elements of plots located in

rural areas [29–32]. One of the components of the rural landscape are the village boundaries. Together with the other elements, they form a complex system of relationships and spaces that create the uniqueness of each landscape.

Cadastral surveying district, also called geodetic district, coinciding in principle with the village area, is the basic area unit of Land Information Systems, related to obtaining, organizing and providing access to widely understood information about the area. Furthermore, the division of the country into statistical regions is consistent with the boundaries of the precincts used in the land and building register. Both cadastral and statistical data provide a complete picture of the area. They are grouped in particular thematic modules, the reference unit of which is the evidential district. In order to fulfil its role properly, the cadastral district should be stable over time. It should not undergo uncontrolled changes. Stability would enable the collection, analysis and comparison of multi-domain data for individual evidential concessions over selected periods of time. The process of shaping village boundaries is a long-term process, which began in the Middle Ages. It may be assumed that in individual time periods boundaries took on "typical" shapes for a given period.

In addition to legal regulations, knowledge of how boundaries were staked in particular historical periods is essential for studying the shape of boundaries. Hypotheses on geometric shapes of village boundaries should be confirmed by analytical methods. The undertaken research may serve as a prelude to further studies on the development and functioning of rural cadastral boundaries.

The issue of the shape of village external borders has been reported so far on the margins of works related to the development of settlements [33–35], on agricultural reforms [36] and an analysis of village internal structure [37–41]. A large number of works in historical geography as well as historical GIS concern the analysis of changes in landscape or land use [42–47]. These works often refer to the boundaries of administrative units, including registration precincts (villages). However, these works do not analyze the genesis of village boundaries (cadastral districts). Shapes of modern villages are very diverse. There are, among others, convex- and concave-shaped villages, villages similar to a square, rectangle or polygon or those with irregular shapes. Various boundary shapes result from an interaction of many factors occurring in our history. One of these factors is undoubtedly the way the borders were designated. Reflections on the shape of a village lead to the examination of delineating elements, i.e., individual village borders. A delimitation line often depended largely on natural conditions. However, boundaries that cannot be explained by natural conditions seem to be of particular interest.

In this paper, the term boundary is taken to mean the line separating the areas of two villages. It is rare for a village to have only one boundary. This can happen only in the case of a village, which is located entirely within the area of another unit. Most often, the village boundary is formed by several boundary lines, each of which separates a given unit from another neighbor.

Research [48] on the development of village borders in the Middle Ages shows that in places with no natural boundaries, delineation of land areas took place by means of the so-called *ujazd* technique [49–51]. The literature to date does not describe how the *ujazd* technique was implemented technically (in geodetic terms). We only find information on who carried out the demarcations and information on the type and location of boundary marks. According to the Dictionary of Old Polish [52], the *ujazd* was marked by conciliators who rode or walked around someone's property to designate its borders and delimit the land area. Literature also provides information on the legal aspect of delimitations–it is accurately described by Smolka [53] and Burszta [54]. The areas (places) of occurrence of the *ujazd* were described by Szulc [51].

Based on the literature on the legal side of demarcations and where they occur, as well as the analysis of the shape of village boundaries on maps from the early 20th century, a research hypothesis was adopted. It was assumed that the boundaries delineated using the *ujazd* technique took on characteristic circular shapes.

Originally, these were circle-like boundaries, i.e., a circular arc corresponding to 400 gon, Figure 1a. Secondarily, with the development of settlements, it was necessary to take into account the already existing boundaries when staking out borders of new villages, and so the new boundaries took the shape of partial circles or circular arcs Figure 1b.
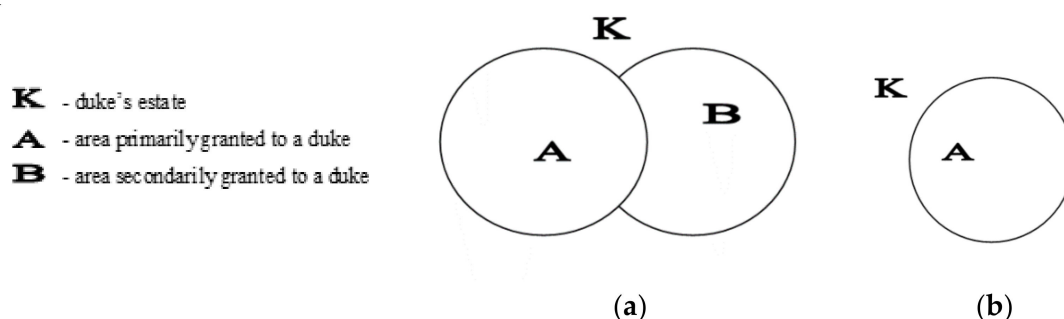

K - duke's estate
A - area primarily granted to a duke
B - area secondarily granted to a duke

(**a**)　　　　(**b**)

Figure 1. Models of demarcation lines formed with the *ujazd* technique. (**a**) Model of the primary demarcation (**b**) Model of the secondary demarcation. Source: based on [48].

The first aim of this study is to confirm the hypothesis of characteristic shapes of boundaries determined by the *ujazd* technique–to define the demarcation technique, i.e., how the first demarcations were carried out. The second aim is to conduct a geometric analysis of village boundaries created in medieval times. The analysis will consist in determining geometric elements of these arcs: their type, radius, length and central angle. A further aim is to indicate the location of the center of the arc, i.e., to ascertain in which area the center of the newly granted area was located.

2. Materials and Methods

Thirteen villages in the Wielkopolska region (Figure 2) the boundaries of which testify to the use of the *ujazd* technique are analyzed. The dates of their origin have been previously determined based on printed sources or scientific studies. The year a village was first mentioned in various sources is given in parentheses next to its name: Dictionary of Polish Kingdom and Other Slavic Countries [55]: Modrze (1253), Popowo (1357), Przysieka (1243), Ryszewo (1310),Szemborowo (1356), Świniary (1396), Wilkowyja (1255), Zdziechowa (1243); Historical and Geographical Dictionary of the Polish Lands during the Middle Ages [56]: Glinka (1170); Hładyłowicz [57]: Gołaszewo (1252), Grochowiska (1136), Lubochnia (1284), Łopienno (1399).

The source material on the position of the village boundaries consists of Prussian topographic 1:25,000 maps from the late nineteenth century, showing the division of cadastral areas. Topographic maps, so called plane-table sheets (Messtischblätter), from 1887–1890 issued by Königlich Preußische Landesaufnahme; Gnesen (sheet 1862), Gonsawa (sheet 1719), Granowo (sheet 2062), Goscieszyn (sheet 1791), Janowitz (sheet 1717), Kletzko (sheet 1789), Mieltschin (sheet 2002), Modliszewko (sheet 1790), Pudewitz (sheet 1931), Rogowo (sheet 1718), Tremessen (sheet 1863). The original copy is in Berlin State Library, signature N14431.

It is known that cadastral boundaries generally coincided with former village borders. In order to determine the extent to which the position of a medieval village changed in the course of the nineteenth century enfranchisement, I used David Gilly's manuscript 1:50,000 map "*Special Karte von Südpreussen*" (the original copy is in Berlin State Library, signature N14431), based on measurements made in 1793–1796. To measure the center of the established area, I used the above-mentioned topographical maps, and contemporary contour and planimetric 1:10,000 maps. Maps of 1975 developed and issued by OPGK (Regional Cartographic Enterprise) in Poznan are in the map repository of the Department of Land Reclamation, Environmental Development and Spatial Management of the University of Life Sciences in Poznan. Older cartographic materials were not used in this study because for the study area older materials usually cover the territory of one village.

Selected materials (especially German topographic maps) cover the whole Wielkopolska and, what is characteristic, despite a scale of 1:25,000, village boundaries are marked on them. As the *ujazd* very often covered the territory of later two or even more villages, these maps made it possible to carry out the research to a greater extent.
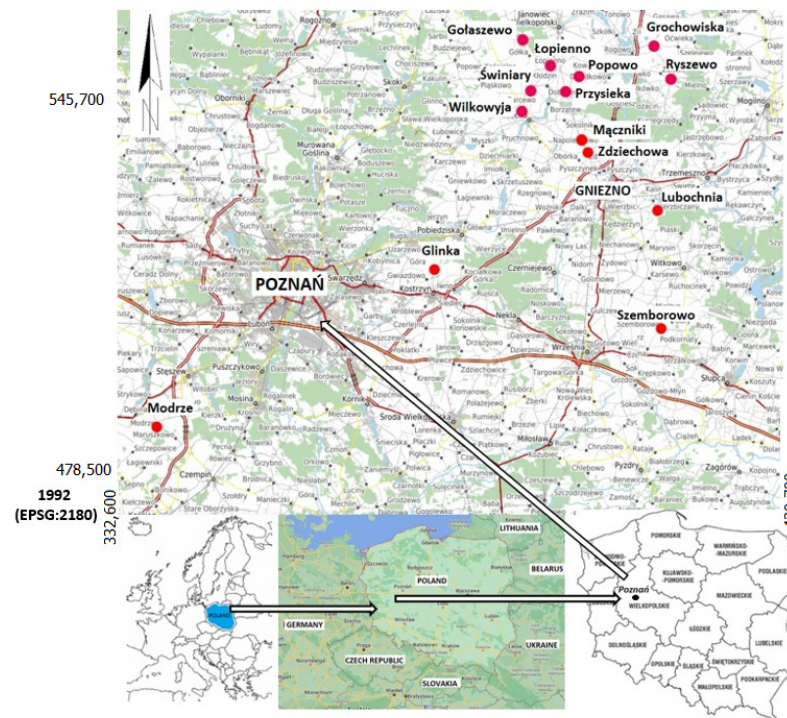

Figure 2. Map showing the location of the analyzed villages. Scale 1:100,000.

The preparatory work involved scanning the objects in the above-mentioned 1:25,000 maps and loading the scans into the MikroMap 4.4 (Coder) program for further analysis. Characteristic markers defining the border were numbered for each object on its boundary line. The points were determined only on those parts of the borders that did not follow natural boundaries and were close to an arc. Using MikroMap, the coordinates of the points on the border line were determined. Calculations were made in WinKalk 3.7 (Coder). Given the scanning and reading errors of the points in the 1:25,000 map, the lengths of the radii and arcs as well as calculated coordinates and position errors of the points were recorded in the nearest tens of meters, whereas the angular measurements were made to the nearest 1 gon.

scanning error 0.0001 m–1:25,000 scale = 2.5 m;
reading error 0.0003 m–1:25,000 scale = 7.5 m;
point position error $\sqrt{7.5^2 + 2.5^2} = 7.9$ m;
segment length error $\sqrt{7.9^2 + 7.9^2} = 11$ m.

The number of the points designated for each village depended on the length and regularity of its border line, as well as the arc's curvature.

The hypothesis is that the arcs designated in the course of the *ujazd* were circular, since it is unlikely that ways of setting more complex curves, such as three-centered, were known in the Middle Ages. However, due to natural conditions or subsequent changes, the shapes of village boundaries delineated with the *ujazd* technique are nowadays rarely found in their pure form. Exceptions to the regular shape may have occurred already in the course of the demarcation due to imperfections of the method, and the blurring of the boundary markers over time, and later as a result of deliberate violations of the border by either neighbor.

I analyzed the longest possible stretches of arc-like boundaries and the largest number of points. The analysis of short segments of the arcs gave unsatisfactory results as the size of the radii diverged from the average and the arc centers were determined at a considerable distance outside a village studied. Where village boundaries did not constitute a single arc, but two arcs of different radii, I attempted to fit individual circular arcs into relevant parts of the borders.

I applied an analytical method to find an arc which best fitted the existing village boundary, i.e., that best approximated the *ujazd* boundary and its center's position. I used Prof. Assoc. Eng. Józef Gil's program, "Approximating measurement results with a circle's equation" [58]. On the basis of the coordinates of the points selected on the border and accurate approximations, the coordinates of the circle's center, the circle's radius, the values of the radius corrections for each of the above-mentioned points, the sum of squared corrections ($[vv]^2$) and the mean error of the circle's center were calculated. Fitting the approximating circle into a village border, the program would find such a position of the circle's center where the sum of squared differences between the actual radius and the radius set was minimal ($[vv] = 0$), i.e., where the mean error of the circle's center position was minimal.

3. Results and Discussions

Firstly, on the basis of an analysis of descriptive and cartographic source materials, a theory was formulated on how land demarcation was carried out in practice using the *ujazd* technique.

It was assumed that a typical *ujazd* followed the following principles. A bonfire was burned in the middle of the newly demarcated area. This could be, for example, a seat of a knight who was granted new land. Designating a border started at some distance from the fire, depending on the size of the area given. This distance was the radius of the arc of the demarcated border. Due to the technique for establishing the border, the new area took the shape of a circle. To be on the border line at all times, they had to follow the tangent to the circle. It was a straight line perpendicular to the line joining a point on the border with the central point marked by the fire. To do so, it was necessary to know how to set a right angle one arm of which passed through the center of the circle, and the second one indicated the direction of the *ujazd* (Figure 3). Those who marked the borders had to constantly orient themselves on the fire. In practice, the frequency of checking this orientation depended on the size of the border arc's radius. Any divergence from the direction of the tangent distorted the circular shape of the border. They sometimes partially changed the shape when they encountered a natural barrier that had to be avoided.
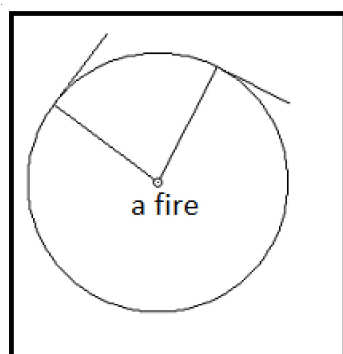

Figure 3. *Ujazd* technique.

As a result of this *ujazd*, the boundary was shaped around the central point, such as a settlement, along with all the lands located there. Borders established with the *ujazd* technique took characteristic shapes. The next stage of research was geometric analysis of borders. For each object on its boundary line, characteristic points marking the course of the boundary were selected and given consecutive numbers.

Table 1 shows the number of points for each object and the distance between successive points (calculated from coordinates).

Table 1. Distance between the points designated on particular objects.

Points No.	Glinka	Gołaszewo	Grochowiska	Lubochnia	Łopienno	Zdziechowa	Modrze	Popowo	Przysieka	Ryszewo	Świniary	Szemborowo	Wilkowyja
1–2	230	300	350	300	770	310	420	620	360	500	130	250	240
2–3	310	220	460	220	280	320	360	430	210	320	270	280	200
3–4	210	250	270	150	270	300	340	480	250	320	200	290	250
4–5	150	170	400	270	470	290	350	490	210	350	170	420	220
5–6	130	200	260	100	360	420	510	490	300	340	250	390	210
6–7	260	240	280	240	330	180	460	380	410	280	280	440	180
7–8	150	230	370	240	240	220	510	290	230	250	190	350	170
8–9	160	280	240	160	250	200	640	370	440	180	310	470	90
9–10	180	220	140	220	310	260	370	370	580	210	290	270	200
10–11	160	270	220	170	750	280	360	320	420	280	190	230	210
11–12	240	210	300	30	480	280	340	450	350	210	200	480	170
12–13	170	260	220	100	300	230	530	280	280	230	290	470	150
13–14	80	310	280	140	210	180	370	490	240	310	350	370	220
14–15	220	170	250	280	350	390	280	290	580	230	290	280	200
15–16	350	190	350	240	250	310	530	210		360	350	380	210
16–17	150	300	380	290	270	180	570	240		310	310	270	210
17–18	290	330	170	260	320	220	580	300		250	300	290	230
18–19	340	340	280	220	420	300	550	310		180	310	300	250
19–20	150	238	210	230	270	340	400	360		350	310	350	
20–21	90	380	330	190	250	260	470	350		110	250	360	
21–22	330	350	290	200	360	210	480	320		180		260	
22–23	200	350	270	170	290	120	380	220		170		290	
23–24	210	350	160	190	270	230	350	490		290		160	
24–25	310	390	210	170	190	310	410	430		310			
25–26	210	420	160		270	250	310	370		310			
26–27	290	370	350		300	300	380	530		150			
27–28	350	380			210	290	210	350		160			
28–29	370	240			270	430	360	270		420			
29–30	300	330			360	340	320	460		230			
30–31	150	330			280	350	360	130		210			
31–32	130	280			350	360	160	420		340			
32–33		280			320	160	420	420		350			
33–34		280			320	280	320			270			
34–35		170			360	250	340			240			
35–36						280	290			300			
36–37						340				370			
37–38						280				470			
38–39						330							
39–40						280							
40–41						300							
41–42						370							
42–43						180							
43–44						360							
Mean distance	220	280	280	200	330	280	400	370	350	280	260	330	200

The table shows that the distances between the points range from about 150 m to about 350 m for the boundaries of smaller villages with higher arc curvature, reaching up

to about 400–550 m for villages with large areas. Deviations from these values occur for additional characteristic points determined on the border line.

Designating an arc's endpoints at a village border in a map was not always so obvious. In some segments, the border line sometimes slightly changed its curvature to return to it at some other point. Therefore, in the first place, the approximating circle was fitted to all the points designated at a single, longest possible arc of the boundary line. The circle's center designated in this way was symbolized as Sw. The approximation results for this case were marked blue in the respective village maps (see Figure 4—Wilkowyja, Figure 5—Zdziechowa, Figure 6—Szemborowo, Figure 7—Gołaszewo, Figure 8—Lubochnia, Figure 9—Glinka, Figure 10—Ryszewo, Figure 11—Łopienno, Figure 12—Grochowiska, Figure 13—Popowo, Przysieka, Figure 14—Świniary, Figure 15—Modrze).
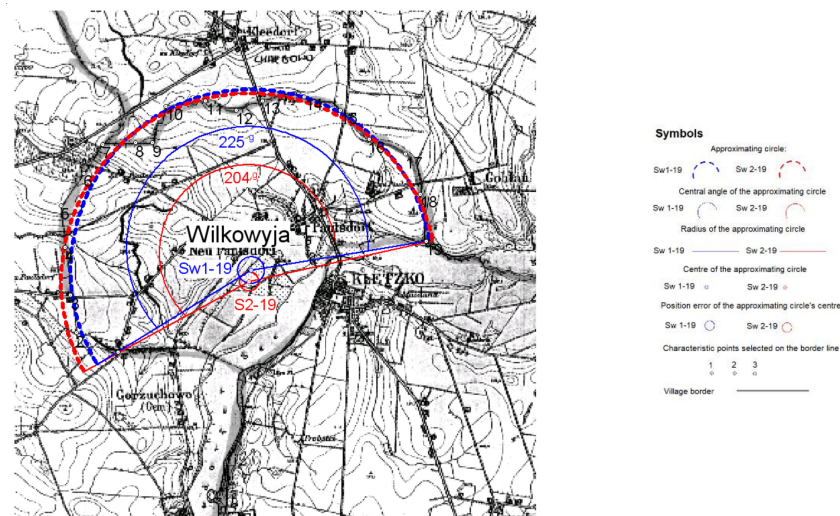

Figure 4. Wilkowyja. The course, position and error of the approximating circle's center: Sw 1—19—approximation of points 1—19; S 2—19—approximation of points 2—19. Scale 1:45,000.
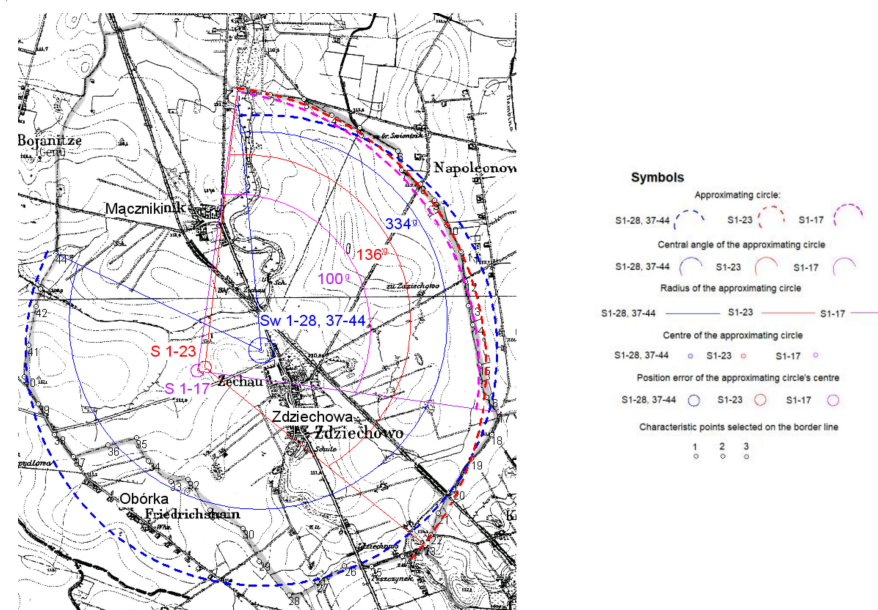

Figure 5. Zdziechowa. The course, position and error of the approximating circle: Sw 1—28, 37—44—approximation of points 1—28 and 37—44—points 29-36 were omitted due to the exclusion of the border between Zdziechowa and Obórka–Obórka village was founded later—in the sixteenth century [55] as the areas of Obora and Zdziechowa villages were separated; S 1—17—approximation of points 1—17; S 1—23—approximation of points 1—23. Scale 1:64,000.
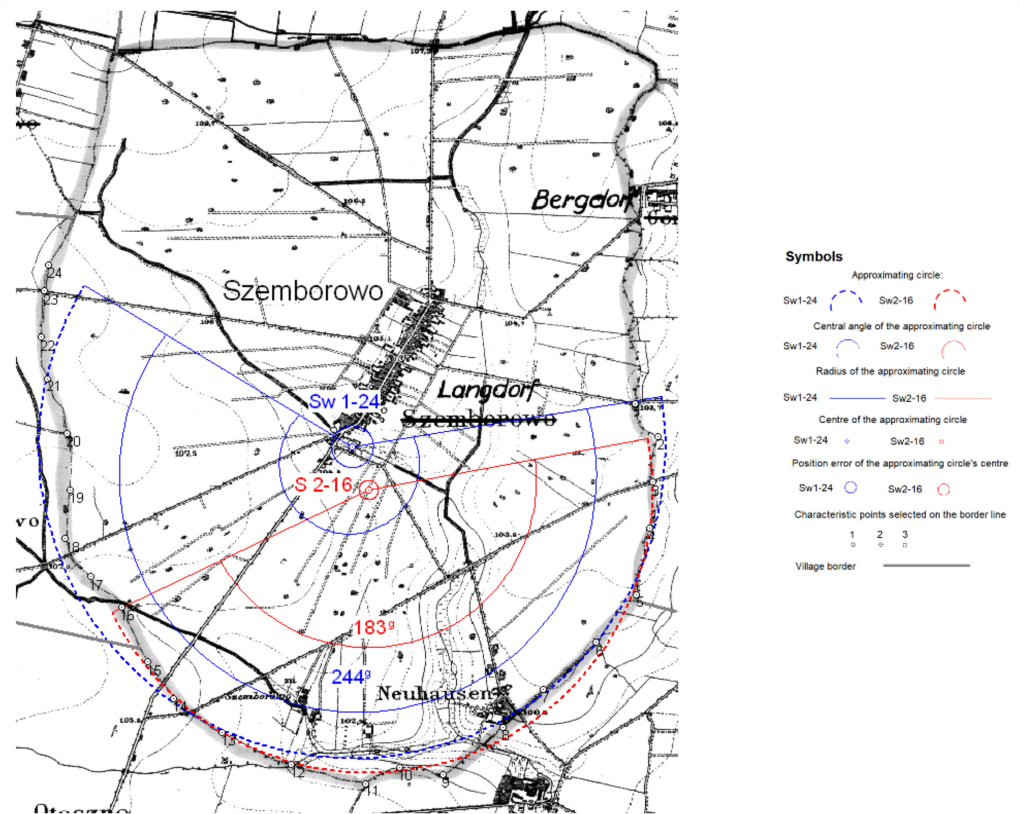
Figure 6. Szemborowo. The course, position and error of the approximating circle: Sw 1—24—approximation of points 1—24; S 2—16—approximation of points 2—16. Scale 1:50,000.
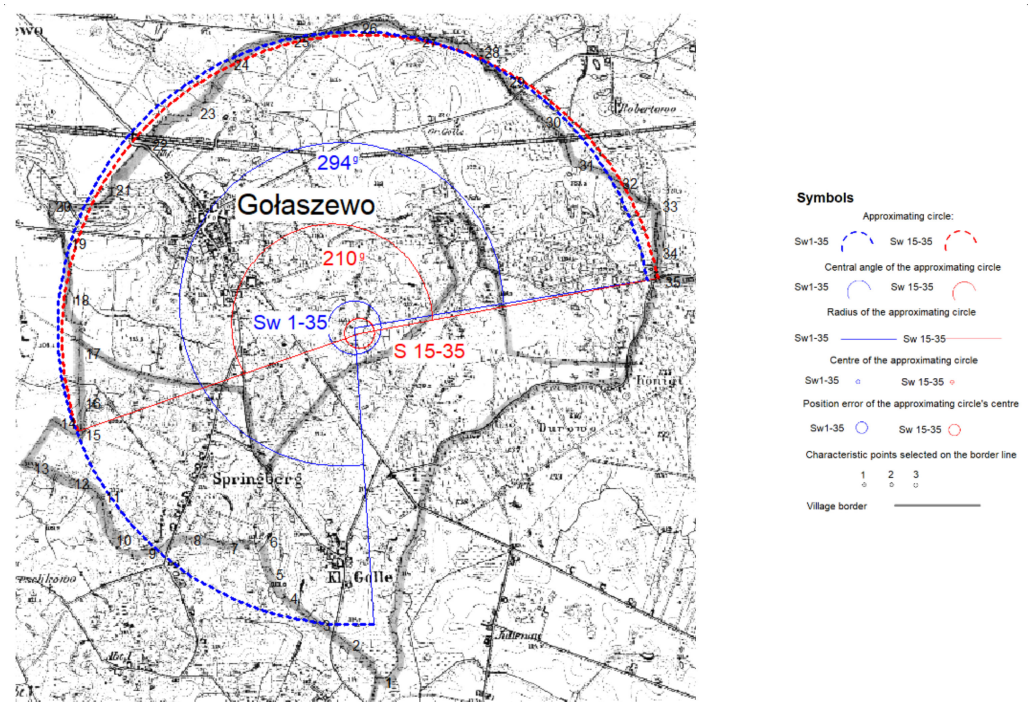

Figure 7. Gołaszewo. The course, position and error of the approximating circle: Sw 1—35—approximation of points 1—35, S 15—35—approximation of points 15—35. Scale 1:50,000.
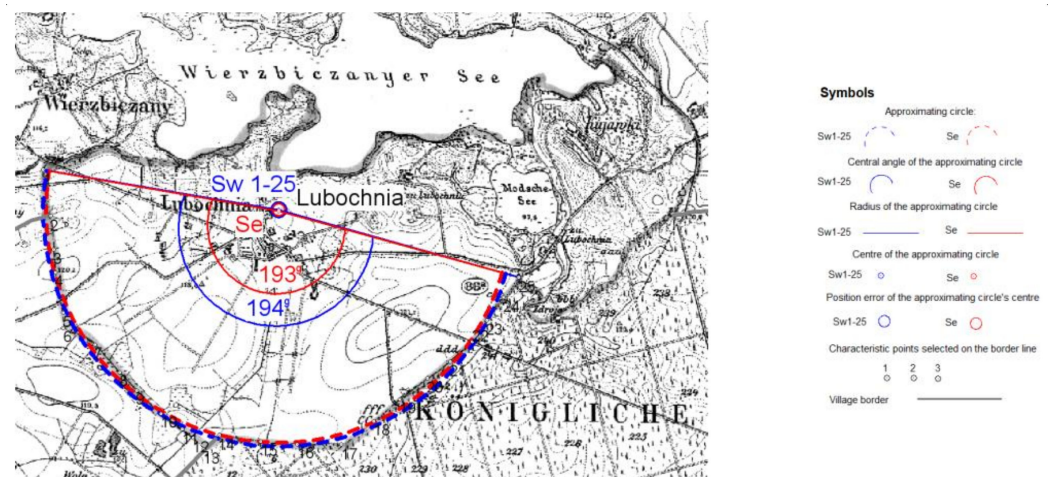
Figure 8. Lubochnia. Course, position and error of the approximating circle: Sw 1—25—approximation of points 1—25, Se—approximation of points 1—25, without points 13, 25. Scale 1:50,000.
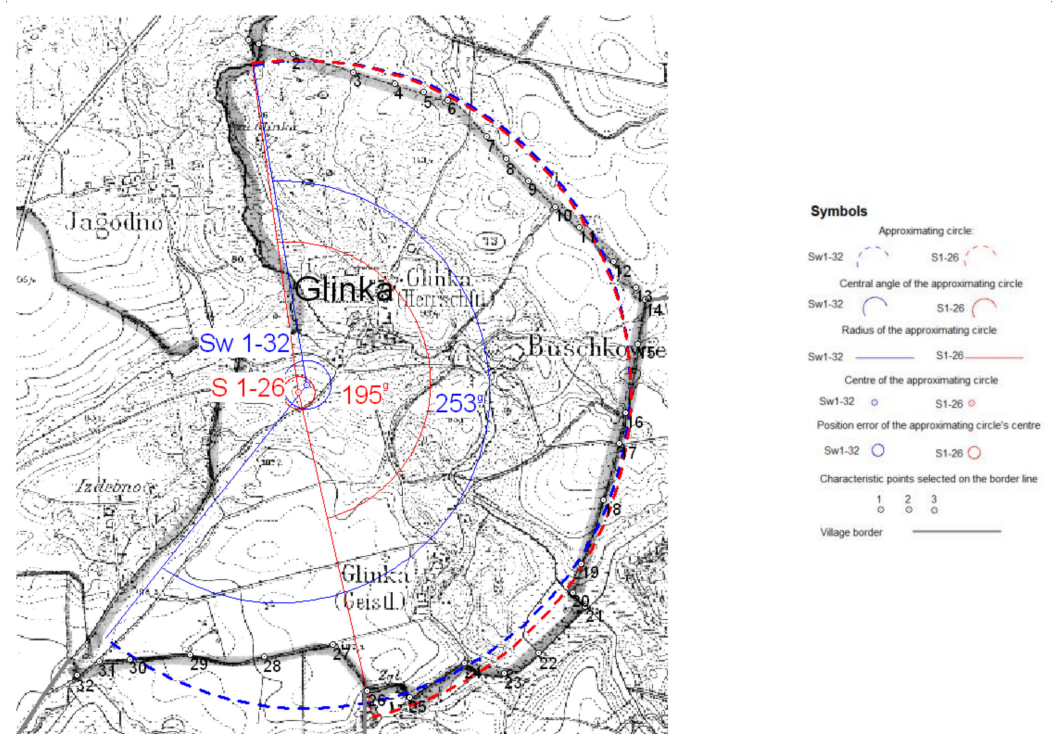

Figure 9. Glinka. Course, position and error of the approximating circle: Sw 1—32—approximation of points 1—32; S 1—26—approximation of points 1—26. Scale 1:43,000.
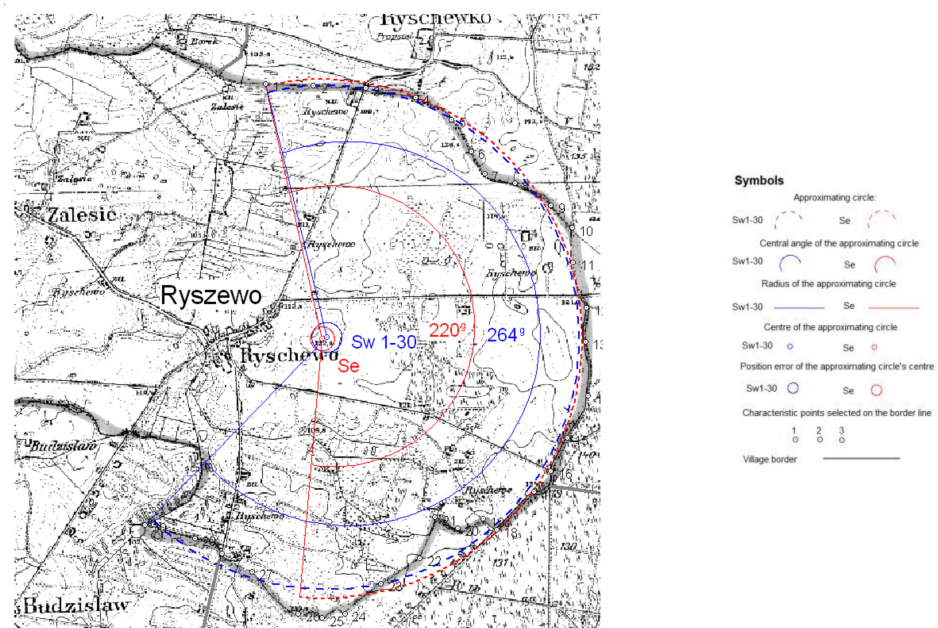
Figure 10. Ryszewo. Course, position and error of the approximating circle: Sw 1—30— approximation of points 1—30, Se—approximation of points 3—28, without points 8, 9, 23. Scale 1:50,000.
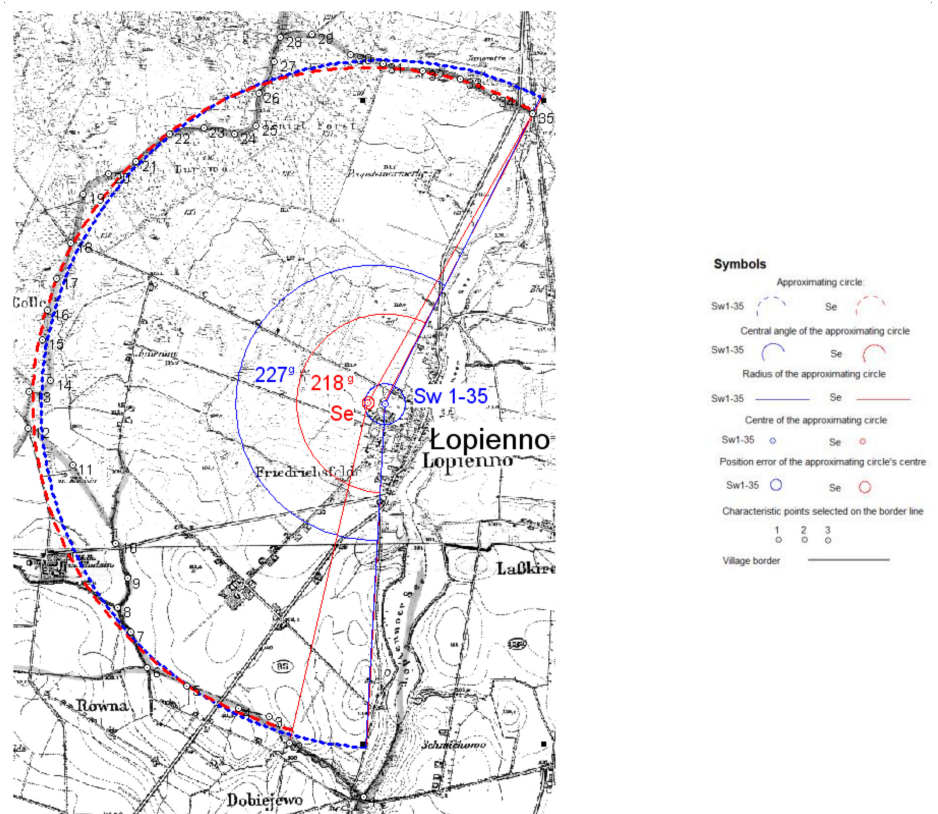

Figure 11. Łopienno. Course, position and error of the approximating circle: Sw 1—35— approximation of points 1—35, Se—approximation of points 2–35, without points 9–14, 19, 23–25, 27–30. Scale 1:64,000.

Figure 12. Grochowiska. Course, position and error of the approximating circle: Sw 7a—27—approximation of points 7a—27, S 10—24—approximation of points 10—24. Scale 1:50,000.

Figure 13. Popowo and Przysieka. Course, position and error of the approximating circle: Popowo: Sw 1—33—approximation of points 1—33, Se—approximation of points 2—15 without point 7; Przysieka: Sw 1a—15a—approximation of points 1a—15a. 1:70,000.
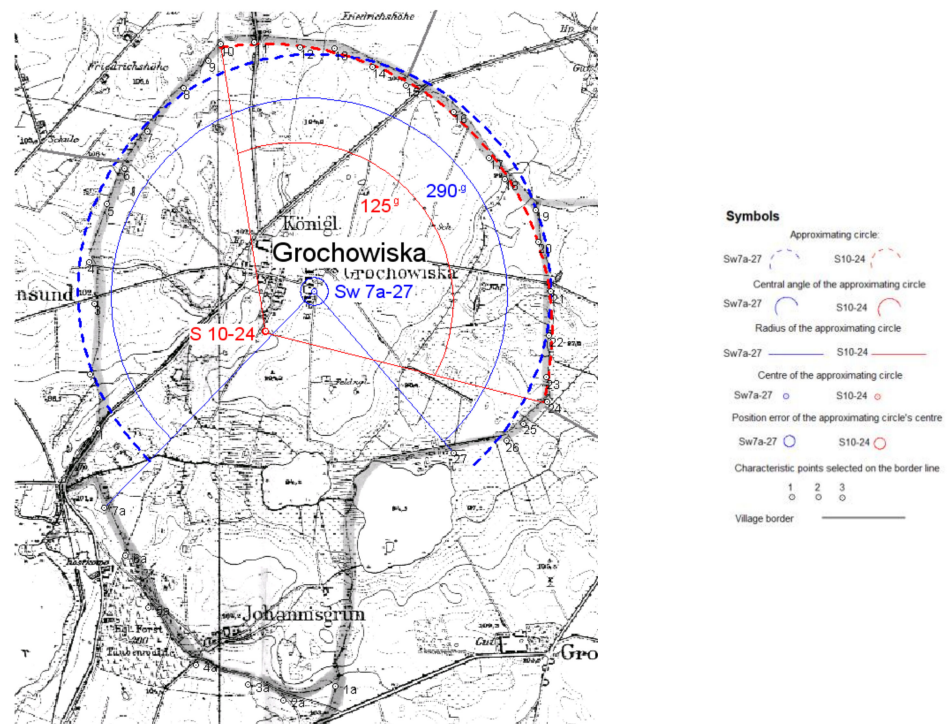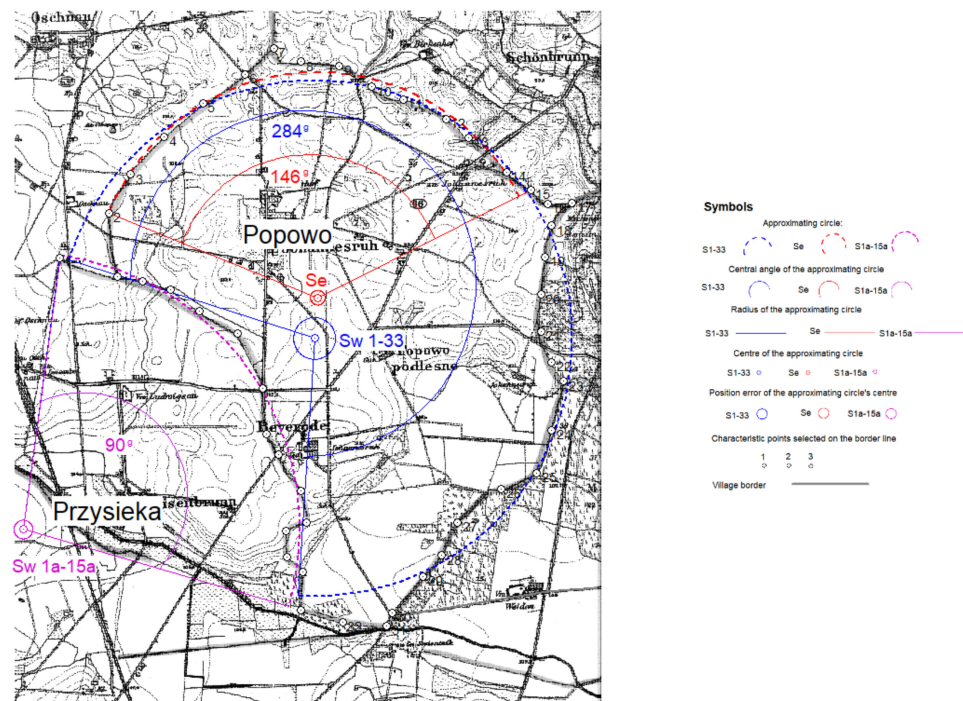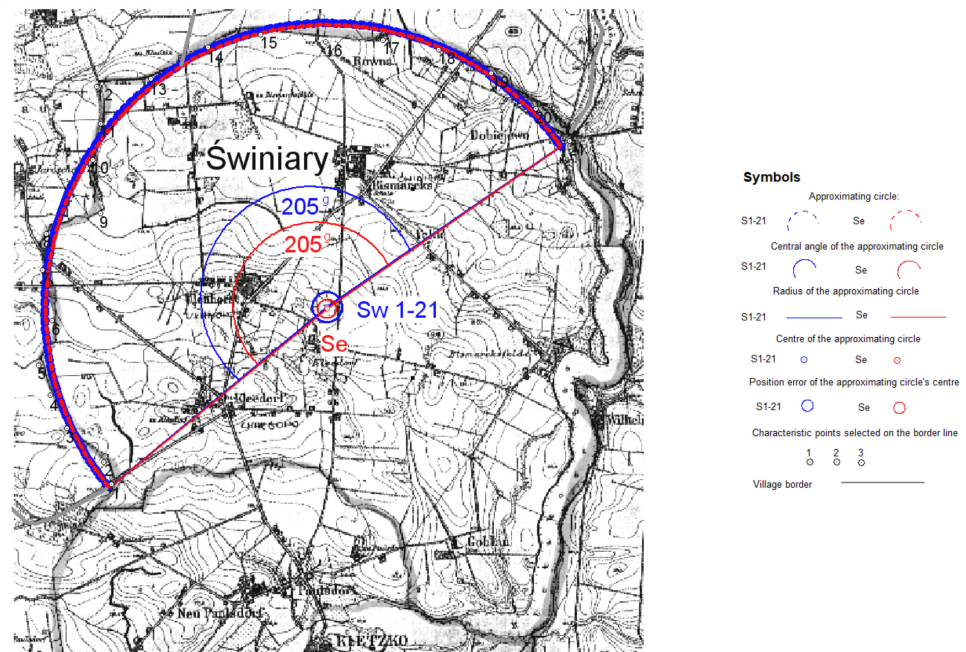
Figure 14. Świniary. Course, position and error of the approximating circle: Sw 1—21—approximation of points 1—21, Se—approximation of points 1—21, without points 9, 12. Scale 1:40,000.
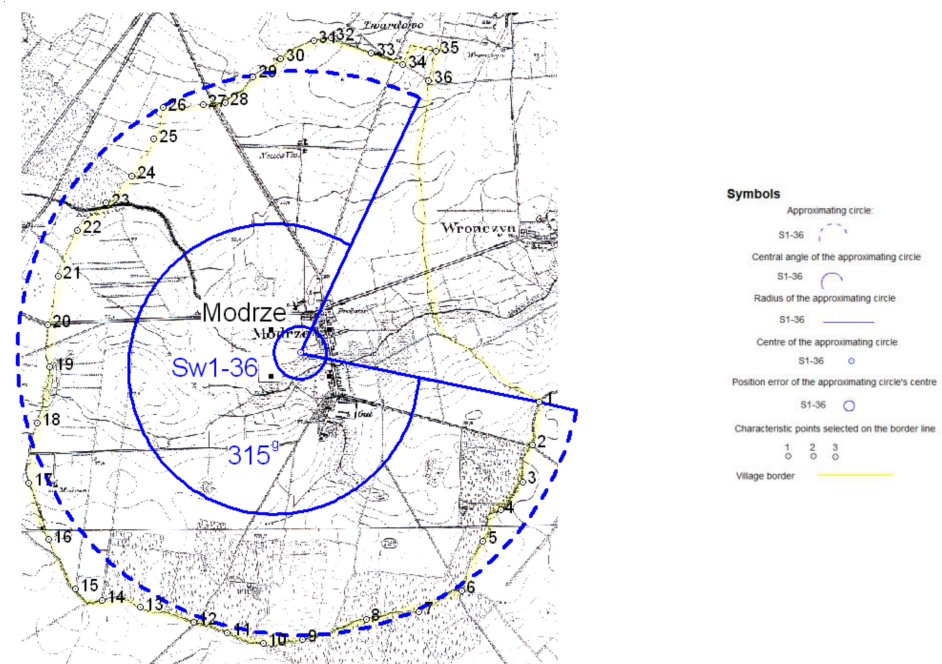
Figure 15. Modrze. Course, position and error of the approximating circle: Sw 1—36—approximation of points 1—36. Scale 1:70,000.

The values of geometric elements of the border approximating circle for all the characteristic points were calculated: the coordinates of the circle's center Sw, radius, central angle, length of the boundary arc, position error of the circle's center, area of the circular sectors corresponding to the boundary arc.

The selected geometric elements of the approximating circle are shown in Table 2.

Table 2. Values of the geometric elements of the boundary approximating circle for all the characteristic points of the arc (Sw).

No.	Village	α [g]	τ [m]	Number of Points	R [m]	±m_o [m]	P [ha]	Approximated Points	Figure Number
1	Glinka Sw 1–32	253	6400	33	1610	120	611	all points	9
2	Gołaszewo Sw 1–35	294	8210	35	1780	160	909	all points	7
3	Grochowiska Sw 7a–27	290	7010	28	1540	90	647	all points	12
4	Lubochnia Sw 1–25	194	4690	25	1540	50	339	all points	8
5	Łopienno Sw 1–35	227	10,260	35	2880	170	1641	all points	11
6	Modrze Sw 1–36	315	17,000	36	2690	250	1935	points 1–36	15
7	Popowo Sw 1–33	284	10,630	33	2470	200	1580	all points	13
8	Przysieka Sw 1a–15a	90	3740	15	2650	90	241	all points	13
9	Ryszewo Sw 1–30	264	6960	30	1680	100	941	all points	10
10	Szemborowo Sw 1–24	244	7430	24	1940	130	837	all points	6
11	Świniary Sw 1–21	205	4890	21	1520	80	378	all points	14
12	Wilkowyja Sw 1–19	225	3360	19	950	70	174	all points	4
13	Zdziechowa Sw 1–28, 37–44	334	11,540	36	2200	120	1457	all without 29-36	5
	mean	248	7860	28	1960	130	899		

Symbols: α—central angle corresponding to the boundary arc (calculated from coordinates), τ—length of the border's arc (calculated from the radius and the central angle), l. point—number of points assigned at the boundary, R—radius of the studied boundary approximating circle, ±m_o—position error of the circle's center (arc), P—area of the circular sectors.

In most analyzed cases (over 65%) the radii of the arcs range from 1500 to 2200 m. The villages with larger values are only Popowo, Łopienno, Modrze (these are the villages of the largest areas) and Przysieka (in this case a small part of the arc-shaped border was analyzed, which could have affected the result). The central angles range from 194 to 334 gon. The exception is Przysieka village (90 g) where only a part of the border was analyzed.

When fitting a circle to all the points of the arc, the position error of the arc's center ranges from 50 to 250 m. It takes the lowest values for the villages the boundaries of which take the shape of a regular arc—e.g., Lubochnia (50 m; see Table 2, No. 4 and Figure 8), Wilkowyja (70 m; see Table 2, No. 12 and Figure 4) or when only a part of the village border in the shape of an arch was analyzed–Świniary (80 m; see Table 2, No. 11 and Figure 14), Grochowiska and Przysieka (in both cases the error was 90 m; see Table 2, No. 3 and Figure 12, and Table 2, No. 8 and Figure 13). The position error of the arc's center takes the greatest value for the villages whose boundaries are in the shape of arcs of different curvature. The attempt to fit the borders of the villages in a circular arc entailed a substantial increase in the average position error of the circle's center—Modrze (250 m; see Table 2, No. 6 and Figure 15), Zdziechowa (240 m; see Table 2, No. 13 and Figure 5). This significant error may indicate that the border resulted from more than just one *ujazd.*

If we take all the characteristic points on the longest possible stretch of a border, the relatively large position error of the circle's center does not allow us either to assess the real accuracy of the border demarcated with the *ujazd* technique or to conduct a more detailed analysis of the topography of the place where the fire burned during the *ujazd*. This led to the exploration and study of the approximating circle and the geometric characteristics of the border after the elimination of some elements of the border. Depending on the course of the boundary lines, the following solutions were applied:

1. Segments of a somewhat different curvature at the endpoints of the boundaries studied were omitted in the following villages: Glinka (see Table 3, no. 1 and Figure 9), Gołaszewo (see Table 3, no. 2 and Figure 7), Szemborowo (see Table 3, no. 3 and Figure 6), Wilkowyja (see Table 3, no. 4 and Figure 4), Zdziechowa (see Table 3, no. 5, 6 and Figure 5).

2. Segments of the border were divided into parts with different curvature by approximating a circle to each part separately in the villages: Grochowiska (see Table 3, no. 7, 8, 9 and Figures 12 and 16), Modrze (see Table 3, no. 10–11 and Figure 17). In

both cases, the arcs' centers were symbolized as the S point no.–the point where the number marked, respectively, the arcs' endpoints, for example, S 3–15.

3. Single points diverging from the border's arc and points for which the difference between the actual radius at a given point and the radius of the approximating circle was very large were eliminated (over 100 m); Lubochnia (see Table 3, No. 12 and Figure 8), Łopienno (see Table 3, No. 13 and Figure 11), Popowo, (see Table 3, No. 14 and Figure 13), Ryszewo (see Table 3, No. 15 and Figure 10), Świniary (see Table 3, No. 16 and Figure 14). In this case, the arcs' centers were indicated with Se.

About 10–15 approximations with elimination whose type depended on the course of the boundary line were carried out for each object, and the results for the best approximations are presented in Table 3.

Reducing the length of the studied segment of the border involved a change of the central angles. The middle angles were correspondingly diminished both when the segments of different curvature were eliminated and when the elimination involved the approximation of a separate part of the border. With the elimination of single points, the radius changes were small and amounted to ±3% (except for Popowo–see Tables 2 and 3).

Table 3. Values of geometric elements of the boundary arcs for the approximation with elimination.

No.	Village	α [g]	τ [m]	Number of Points	R [m]	$\pm m_o$ [m]	Approximated Points	Figure Number
				1. Elimination of segments of different curvature.				
1	Glinka S 1–26	195	5050	27	1650	80	points 1–26	9
2	Gołaszewo S 15–35	210	5900	21	1790	90	points 15–35	7
3	Szemborowo S 2–16	183	5060	15	1760	60	points 2–16	6
4	Wilkowyja S 2–19	204	3170	18	990	50	points 2–19	4
5	Zdziechowa S 1–23	136	5640	23	2640	60	points 1–23	5
6	Zdziechowa S 1–17	100	4150	17	2640	60	points 1–17	5
	mean	171	4830	20	1910	70		
				2. Parts of the borders of different curvature, approximated separately				
7	Grochowiska S 2a–10	121	5050	16	2660	70	points 2a–10 (2a–7a and 1–10)	16
8	Grochowiska S 10–2a	191	6480	17	2160	50	points 10–2a	16
9	Grochowiska S 10–24	125	3670	15	1870	20	points 10–24	12
10	Modrze S 1–14	135	5450	14	2570	80	points 1–14	17
11	Modrze S 14–28	107	5750	15	3420	90	points 14–28	17
	mean	140	5280	15	2540	60		
				3. Elimination of single points on the boundary line				
12	Lubochnia Se	193	4610	23	1520	40	All points without 13, 25	8
13	Łopienno Se	227	9620	19	2810	50	points 2–35, without 9–14, 19, 23–25, 27–30	11
14	Popowo Se	146	4950	13	2160	70	points 2–15, without 7	13
15	Ryszewo Se	220	5980	23	1730	80	points 3–28, without 8, 9, 23	10
16	Świniary Se	205	4890	19	1520	50	all points without 9, 12	14
	mean	198	6010	19	1950	60		
	Mean for all	169	5340	18	2120	60		

Symbols: α–central angle corresponding to the border (calculated from coordinates), τ–length of the border's arc (calculated from the radius and central angle), l. point–number of points assigned at the boundary, R–radius of the studied boundary approximating circle, $\pm m_o$–position error of the circle's center.
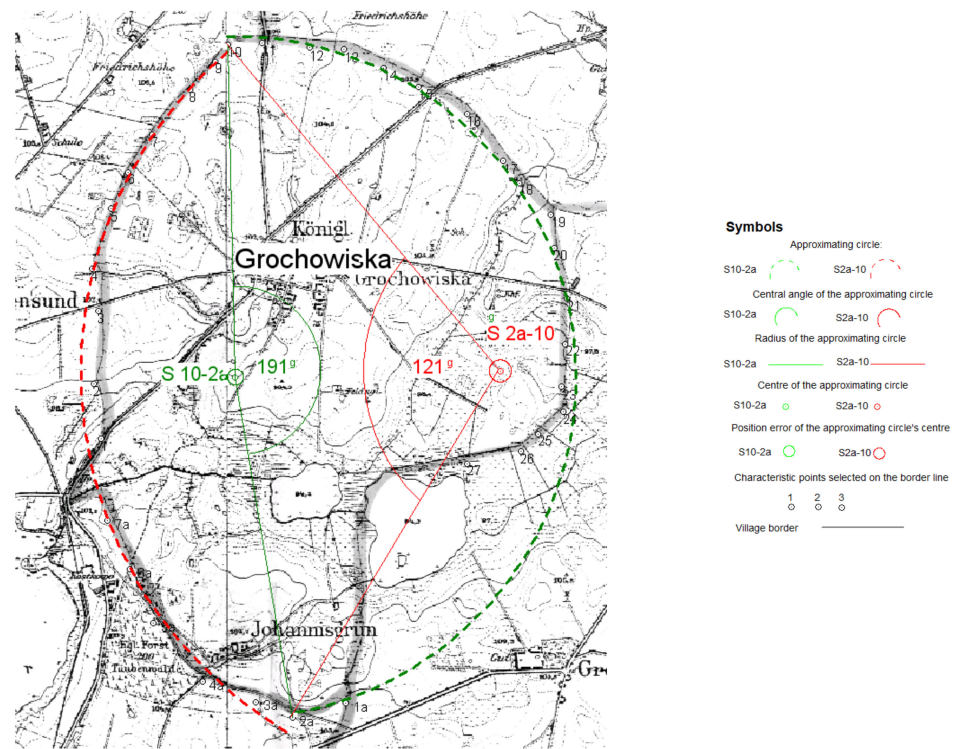
Figure 16. Grochowiska. Course, position and error of the approximating circle: S 10—2a—approximation of points 10—2a, S 2a—-10—approximation of points 2a-10. Scale 1:50,000.
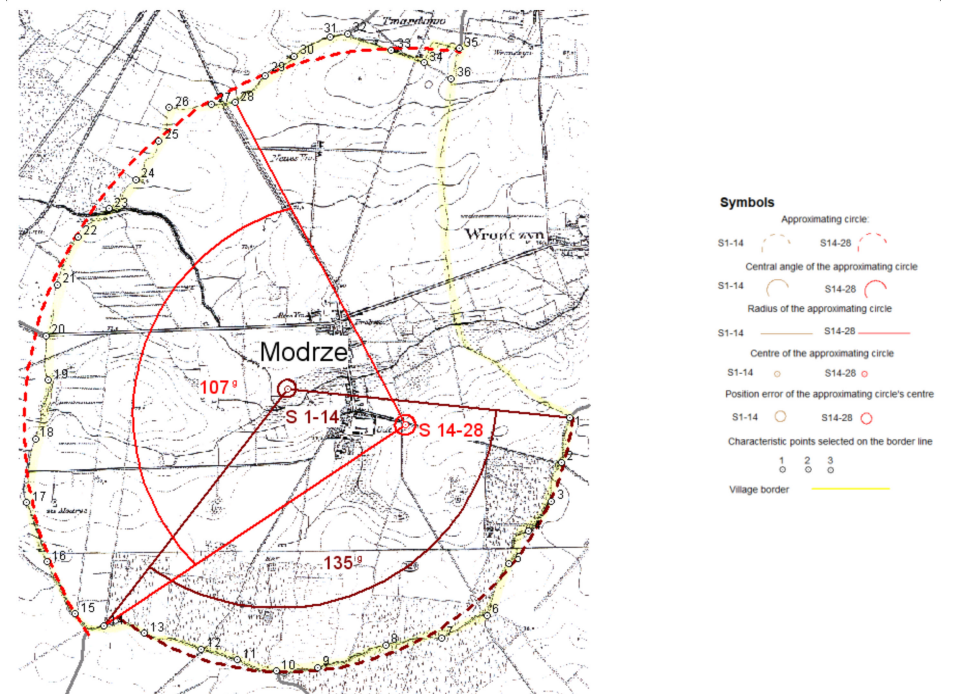

Figure 17. Modrze. Course, position and error of the approximating circle: S 1—14–approximation of points 1—14; S 14—28–approximation of points 14—28. Scale 1:70,000.

The difference between the radius of the circle approximating all the points and the radius of the approximating circle with the elimination of points usually did not exceed 50 m. Examples include the elimination for Ryszewo village–Se (the difference was 50 m) and Lubochnia village–Se (the difference was 40 m). For Świniary the length of the radius

Se did not change after elimination. As for Popowo the length of the radius was reduced by over 12% due to the fact that with the elimination of points, a segment of a slightly different curvature was excluded.

The difference in the lengths between the radius of the circle approximating all the points and the radius of the circle approximating the border with the elimination of a segment of a slightly different curvature at the endpoints of the border studied were higher and amounted to ±0.5–20%. The shorter the omitted segment of the boundary line was, the smaller was the difference between the lengths of the radius of the circle approximating the border with elimination and the radius of the circle approximating all the points.

The lengths of the radii calculated using elimination, which consisted in dividing the border into parts of different curvature by approximating a circle to each part separately, most differed from the radius of the circle approximating all the points and amounted to ±21–72%. Increasing the radius by 72%—Grochowiska S 2a-10—resulted from an attempt to fit the approximating circle into the points that were not taken into account for the circle approximating Sw. These differences pointed to a more accurate approximation after elimination of some points and extreme arc's segments, which was best reflected in the value of the position errors of the circle's center.

The elimination of single points had no significant influence on the change of the arc's center location. It is worth noting that in many cases, after selecting circles of an average position error of the center Sw and arc centers from individual eliminations in the map, the circles had the centers of all approximations, such as Gołaszewo (Figure 7), Lubochnia (Figure 8), Glinka (Figure 9), Ryszewo (Figure 10), Łopienno (Figure 11), Świniary (Figure 12). The elimination, however, clearly reduced the mean value of the position error of the circle's center-mo-on average by about 48%. The greatest average error of the circle's center was reduced for those villages where one circle was replaced with circles approximating border segments (Grochowiska, Modrze) and for the villages where the elimination of points diverging from the border line was applied (Łopienno).

4. Conclusions

The results confirm the circular nature of the boundary arcs marked around an area's center. Most of the arcs' radii ranged from 1500 to 2200 m and the central angles ranged from 90 to over 330 gon.

When establishing borders with the *ujazd* technique, there were cases of derogation from the circular shape of the border because of natural conditions. They would bind a boundary line to characteristic natural markers in the vicinity or change the course of the boundary line because of a natural barrier. Lubochnia is an example of such a change in the course of the boundary line (Figure 8) as it creates a distinctive circular sector based on the lake. In this case, we can set up two hypotheses. The first suggests that the change in the course of the boundary line after point 25 was caused by the allocation of the entire water source (intake) to Lubochnia (marked as Zdroje in the map). The second hypothesis suggests that the reason for changing the course of the boundary line could have been an obstacle in getting to the shore of Lubochnia Lake in the form of Modrze Lake. If the course of the boundary line had not been changed after point 25, the border of Lubochnia would not have covered the entire lake and land on its south-eastern shore. Therefore, the ujzad technique was later applied in the current area of Lubochnia, known as Kujawki.

As for Grochowiska (Figures 12 and 16), it can be assumed that the distorted circle's course S 10-2a is due to the fact that during demarcation they probably tried to divide the lake into two equal parts, one for each separated area. It is not known when the division took place: at the time of the *ujazd* (S 10-24) or later (S 10-2a).

The calculated centers of the circular arcs and the boundary line drawn in the maps show that a distinctive natural marker was the center of an area granted (where the fire burned). In the thirteen analyzed villages, the circle's center was:

1. In three cases, on an elevated terrain (Figure 7—Gołaszewo, Figure 9—Glinka, Figure 10—Ryszewo).

2. In seven cases, next to village buildings or in its center (Figure 11—Łopienno, Figure 6—Szemborowo, Figure 12—Grochowiska, Figure 8—Lubochnia, Figure 4—Wilkowyja, Figure 5—Zdziechowa, Figures 15 and 17—Modrze). A comparison of the location of village buildings in 1:25,000 maps from the late nineteenth century and David Gilly's map proves that it has not changed since the end of the eighteenth century. It can thus be assumed that it corresponds to their position from the demarcation times.

3. In two cases (Figure 14–Świniary, Figure 13–Popowo and Przysieka), the arcs' centers were outside the present village buildings–they might have been related to settlements that have not survived to our times. As for the boundaries of Popowo, whose name indicates an old origin of the village, we can assume that they arose as a result of more than just one *ujazd*.

Using the method of a border approximated with a circle confirms that a border was designated with the *ujazd* technique around the central (middle) point of an area granted where a fire burned. We could test the applied method of determining the *ujazd* arc's center by conducting archaeological research at an alleged fire site.

The relatively large position error of the arc's center may be due to several reasons. A significant source of the error may be the demarcation technique used at that time: smoke from the fire, around which the *ujazd* was performed, could have been difficult to see or the wind could have changed its direction. Another reason could have been a lack of sufficient skills of those who conducted the demarcation. Straightening the boundary line (which originally took the shape of an arc) between particular points may largely affect the average position error of the approximating circle's center. An example is Glinka (Figure 9) having the shape of a circular sector where the segments between the points (1–6, 6–14, 14–20) have the shape of straight lines. Other subsequent changes in the boundaries studied may also have had an impact on the significant value of the presently determined average position error of the center of the circle approximating all the points.

The significant position error of the approximating circle's center (±200 m) may indicate that the border is not the result of one *ujazd*. Perhaps a change of the fire location (i.e., the arc's center) occurred during the demarcation as the previous fire was not visible. It is also likely that these fragments resulted from a separate delimitation. This assumption may be confirmed by the approximation of Grochowiska borders with two circles with their centers in points S 2a-10 and S 10-2a (Figure 16). In these cases, the mean position error of the circle's center was significantly reduced in comparison with the error of the arc's center Sw 7a-27 (Figure 12) and the coincidence of circles with the actual boundary line. Figure 12 also presents an approximating circle with the center at point S 10-24–the mean position error of the center reached the lowest value–20 m. Modrze is another example demonstrating the creation of village boundaries with two applications of *ujazd* (Figure 15). When the border of Modrze was fitted in two circles (Figure 17), they better covered the actual course of the boundary line, while the average position error of their centers was reduced.

The position errors of the circles' centers after the elimination of some elements of the border were significantly reduced compared with the errors in approximation of all the points designated on the boundary lines. It seems that the average position errors of the circle's center after the elimination to a greater extent reflect the actual accuracy of the *ujazd* delimitation technique, and at least determine the upper limit of the error. It can thus be assumed that when staking out borders with the *ujazd* technique, deviations from the ideal circle did not exceed approximately ±60 m.

The medieval boundaries preserved to our times are residual in nature. This is due to the changes in the course of boundaries over time. They resulted both from further settlement processes (founding new villages, merging the land of adjacent villages) and from the violation of boundaries during the development of land adjacent to the village boundaries.

Since the study of medieval village boundaries covered only the Wielkopolska region, it should be supplemented in the future with an analysis of boundary shapes in other areas

of Poland and Europe. Further research on shaping village boundaries in the medieval period should attempt to determine the actual accuracy of the *ujazd* technique, as well as to investigate the possibility of using other methods of marking out large radius arcs.

One such method mentioned in the sources is demarcation based on the position of the sun. This method is not further described. The only information we can find in documents on this subject is that the condition for demarcation was a visible sun, according to which the direction of demarcation was indicated. Demarcations were not carried out on cloudy days–they were interrupted when the sun set and continued when the sun rose [17]. It would be interesting to compare the results of the "method by sun" with the method presented in the paper. Perhaps a more interdisciplinary approach will be needed here–a turn towards astronomy and historical geography. One of the main advantages of historical geography [59] is that it tends to look at localities as a whole in relation to the surrounding territory. Combining knowledge of historical geography with legal theory and surveying can provide insights into the processes that had a decisive role in the formation of village boundaries and cadastral districts.

The village demarcations presented in this paper using the *ujazd* technique were used for the granting of land and were the first linear boundaries to form the nucleus of village boundaries. Most linear boundaries in the Middle Ages surrounded estates [28,60,61] and confirms that "when there was a reason for a linear frontier, people from the middle age have proven that they know very well how to do so" [61].

There is no doubt that historical village boundaries from the Middle Ages that have survived to the present day have a historic character due to their antiquity and should be protected. This protection should cover not only selected but all rural landscapes [62] The study of the constancy of spatial elements allows us to understand the processes of landscape change in the past [12]. The cultural landscape, which is a measure of the development of society [63], also influences the current development of the countryside [10].

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