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Methodology of assessing quality of spatial data describing course of shoreline as tool supporting water resource management process

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Abstract: The proper management of water resources is currently an important issue, not only in Poland, but also worldwide. Water resource management involves various activities including monitoring, modelling, assessment and designing the condition and extent of waters sources. The efficient management of water resources is essential, especially in rural areas where it ensures greater stability and efficiency of production in all sectors of the economy and leads to the well-being of the ecosystem.

The performed analyses have demonstrated that the time of origin of the cadastral data defining the course of water boundaries has a significant effect on their quality. Having analysed the factors (timeliness, completeness, redundancy) used to assess the quality of cadastral data, their clear trend of changes in time was noticed. Thus, it is possible to specify the estimated degree of quality of cadastral data defining the course of watercourse boundaries only based on the information about the method, time and area of data origin in the context of the former partition sector.

This research paper presents an original method of assessing the quality of spatial data that is used to determine the course of the shoreline of natural watercourses with unregulated channels flowing through agricultural land.

The research has also demonstrated that in order to increase the efficiency of work, the smallest number of principal factors should be selected for the final analysis. Limiting the analyses to a smaller number of factors does not affect the final result, yet it definitely reduces the amount of work.

Keywords: data quality, data validity, shoreline, water resource management

INTRODUCTION

Poland is classified as a country with poor water resources (Małecki and Gołębiak, 2012). Its water sources amount to, on average, approximately $60 \cdot 10^9$ m^3 per year (GUS, 2020). Poland's water sources mainly come from atmospheric precipitation, which is characterised by high temporal and territorial variability (Gutry-Korycka *et al.*, 2014). This results in periodic water surpluses and deficits (GUS, 2020), which is why it is so important that the country's water resource management process is effective and efficient. Poland's water resources are mainly used for the production needs of the national economy (industry – 68%; agriculture – 9%) and for the needs of the population (23%). According to GUS (2020), the country's main source of water used to supply the domestic economy is surface water, which covers approximately 80% of the demand. Surface water is mainly used for production purposes in industry and agriculture. Groundwater, due to its better quality than surface water, is mainly used as drinking water supply (Sadurski and Przytuła, 2016; GUS, 2020). The proper management of water resources is currently an important issue, as the quantity and quality of freshwater supplies are decreasing not only in Poland, but also worldwide (Elkharbotly, Seddik and Khalifa, 2022). Water resource management involves various activities including monitoring, modelling, assessment and designing the condition and extent of waters sources (S.S. Ahmed *et al.*, 2021). These can be divided into national and international, as well as short-term and long-term, activities. The proper management of water resources involves the analysis of numerous factors. Currently multi-criteria analysis models are used, which have their advantages and disadvantages (Jaiswal, Lohani and Tiwari, 2021).

When managing water resources, various factors – social, ecological, technical, economic, topographic, political and legal – must be analysed (da S. Alves *et al.*, 2021; Elkharbotly, Seddik and Khalifa, 2022). One should also consider such elements as: water flow in a given area, geological structure, slope or proximity to surface waters (Tafila *et al.*, 2022). Moreover, as indicated by Zhang *et al.* (2019), and A. Ahmed *et al.* (2021), in order to be able to manage water well, it is necessary to know its location, which is helpful in planning water demand. To determine the location of the water, spatial data is necessary to define water boundaries on the ground which, according to Polish law, is the same as the shoreline. Spatial data describing the course of the water boundary is captured by surveying methods. The methods used to determine the course of the shoreline are direct field measurement methods that use precise positioning techniques GPS (Pajak and Leatherman, 2002) as well as photogrammetric and remote sensing methods (Redman, 1992; Di, Ma and Li, 2001). After the shoreline has been surveyed, its course is presented on geodetic maps. As stated in Wet de and Odume (2019), and Sechu *et al.* (2022), water resources should be managed in a way that is effective and does not harm the environment at the same time. The proper management of water resources should be based on sustainable development (Mohammed *et al.*, 2022). Effective water resource management is especially important in rural areas where it ensures greater stability and efficiency of production in all sectors of the economy and leads to the well-being of the ecosystem (S.S. Ahmed *et al.*, 2021). Limited water resources threaten crops that are closely related to social and economic development (Lv *et al.* 2021).

Agricultural land in Poland accounts for 18,760,000 ha, which is about 60% of the entire land area of the country, 70% of all agricultural land in Poland is farmed GUS,(2019). The mean average size of an agricultural farm in the country in 2018 was 10.81 ha, though as many as 75% of farms GUS (2019) covered an area below the mean national average. Land fragmentation in individual farms in Poland poses a big problem, especially in the south of the country (Cegielska *et al.*, 2018). It is a worldwide challenge and land fragmentation currently has a negative effect on the productivity and efficiency of farms across the globe (Manjunatha *et al.*, 2013). One of the methods for improving the spatial structure of agricultural land, and consequently increasing the efficiency of farms, may be consolidation (Janus and Markuszewska, 2017). However, land consolidation is a complicated and lengthy process (Leń, 2018). An easier way to improve the spatial structure of farms by increasing their area may be land trade on the free market. However, it is impossible to trade in land if the legal status of this land is undetermined (Kwartnik-Pruc and Mączyńska, 2019; Kwartnik-Pruc and Mączyńska, 2020; Kwartnik-Pruc and Trembecka, 2021).

Natural watercourses have a significant influence on limiting agricultural land trading. Pursuant to Polish law, land covered with flowing water becomes the property of the owner of the water, which is the State Treasury (Water Act, 2017). In the event that flowing water starts occurring on land that is not owned by the State Treasury, the owner of this land switches to a public entity, i.e. the State Treasury. Should water start flowing permanently across land that is not owned by the State Treasury, the land occupied by the water should be geodetically separated from the adjacent agricultural land. The boundary of subdivision in this case is a determined shoreline. Without the geodetic separation of the part of the land newly covered by water from the remaining land, land trading is impossible (Kwartnik-Pruc, 2016; Mączyńska and Kwartnik-Pruc, 2016). In Poland, the shoreline is a materialised boundary that marks the extent of not only flowing water and land occupied by water but, most importantly, the extent of property rights. The shoreline is also the boundary that delimits the extent of natural water resources. In Poland, the shoreline of natural watercourses is determined in administrative proceedings according to three criteria. First of all, the shoreline is drawn along the distinct edge of the shore, if one exists. The upper edge of the slope is considered to be the distinct edge of the shore. However, if there is no distinct edge of the shore, the shoreline runs along the boundary of permanent grass growth. However, if the boundary of permanent grass growth is above the average water level from at least the last 10 years, then the shoreline runs along the line of intersection of the water table (according to the average water level for the last 10 years) with the adjacent ground. The model for determining the course of the shoreline proposed by the Polish legislator is unique. In the countries of Western Europe, Australia or the United States, the shoreline is determined according to the central line of the water (Arkansas v. Tennessee 1918; Cooke, 2003; Regulation 2012).

In Poland, the course of the shoreline is recorded in the register of land and buildings on cadastral maps, because the watercourse shoreline is also the boundary of the cadastral parcel. Natural watercourses with unregulated channels naturally change their courses, causing not only a change in their ownership, but also changes in boundaries of cadastral parcels and their area (Bieda, 2010; Bieda, Bydłosz and Parzych, 2013). Due to the high dynamics of changes in the boundaries of watercourses over time, it is necessary to constantly update the data entered into the register of land and buildings, which defines the course of the shoreline. It will enable trade in agricultural land adjacent to watercourses, which will improve the spatial structure of agricultural land by increasing the efficiency and productivity of individual farms. The correct determination of water boundaries (the shoreline) is also very important because, as stated in Bluemling, Tai and Choe (2021), well-defined boundaries form the basis of the effective and efficient management of natural resources. Boundaries play a significant role in building confidence in integrated water resource management (Nachlik, Buczek and Mazoń, 2005). Correctly defined natural resource boundaries are the foundation on which design activities necessary for effective water resource management are based. Resource boundaries are also used in the process of monitoring and modelling the condition and extent of waters.

In order to eliminate the problem resulting from the inability to trade in agricultural land, the authors of this research paper present an original methodology for identifying areas in which the degree of obsolescence of the data determining the course of the shoreline is so large that it requires updating. The study also develops the criteria for the hierarchy of urgency of updating work performance in order to define the areas for which determining the course of the shoreline of watercourses flowing through agricultural areas should be of prime importance. Defining the areas that require updating the water boundary will not only eliminate the problem with agricultural land market turnover in Poland, but also increase the efficiency of small farms. The method proposed in this research paper will also support the process of managing natural water resources. The correctly defined boundaries of water resources form the basis for effective water resource management, which should be based on sustainable development. The research was carried out with the use of GIS tools, that are now widely used in all fields of science. The analyses also took into account the historical aspect of establishing a cadastre in Poland, as historical conditions meant that various cadastral systems functioned here in the past (Fedorowski, 1974; Wilkowski, 2005; Mika, 2010), defining the course of cadastral boundaries with unequal accuracy (Mączyńska 2018).

This research paper also proposes the method of developing the criteria for the hierarchy of urgency of updating work performance for data defining the course of water boundaries. This method is based on the assessment of the quality of spatial data describing a given problem or phenomenon, according to the methodology proposed in the paper. The original methodology for assessing the quality of spatial data developed by the authors is a versatile one. It can be effectively used for all kinds of spatial data that take the form of closed polygons. The authors proposed the use of generally available and increasingly popular GIS tools to assess the quality of spatial data so that the proposed method could be successfully used for any part of the world. The solutions presented in the paper can be applied to spatial data describing other phenomena, not only those related to flowing waters. The only requirement is the possession of spatial data describing a specific problem. Today, spatial data is generally available as the current problem is not a lack of spatial data, but its quality (Bielecka and Burek, 2019).

So far, GIS analyses have been used as tools supporting the decision-making process in multi-criteria management of natural resources of ground and flowing waters around the world, e.g. in India (Rajasekhar *et al.*, 2019); Pakistan (Arshad *et al.*, 2020), Korea (Lee, Hong and Jung, 2018) or Ethiopia (Meresa and Taye, 2019). A novelty is the use of GIS tools and GIS spatial analyses for the full and versatile assessment of the quality of spatial data describing various phenomena and taking the form of closed spatial polygons.

The general scheme of developing the criteria for the hierarchy of urgency of updating work performance for any spatial data describing the problem to be examined is presented below in Figure 1. This original model developed by the authors is based on the estimation of the quality of spatial data made according to the methodology they propose (Fig. 1).

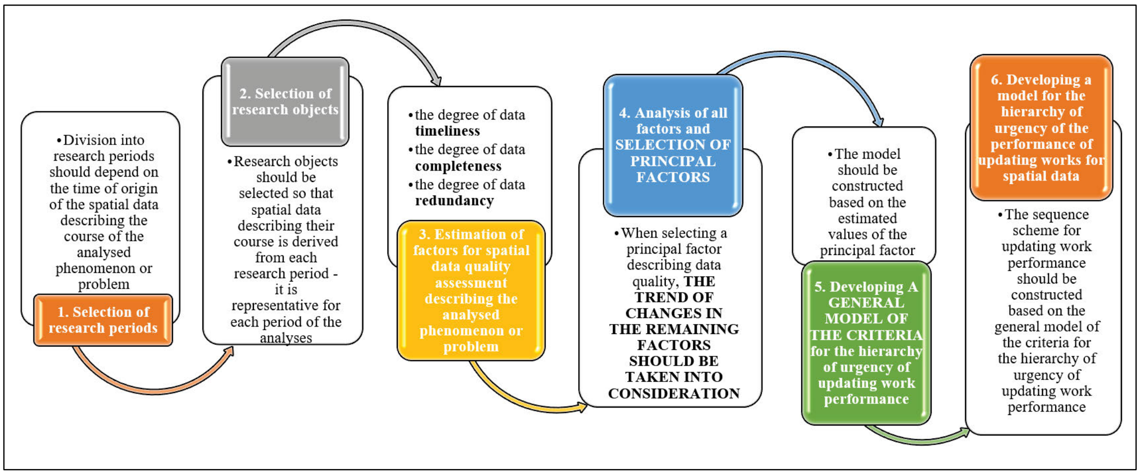

Fig. 1. General diagram of the analyses performed; source: own elaboration

MATERIALS AND METHODS

GENERAL INFORMATIONS

This chapter presents the original method of assessing the quality of spatial data determining the course of water boundaries. The focus is also on identifying those areas where the degree of obsolescence of the shoreline data is so large that it requires updating. All analyses aimed at assessing the quality of spatial data determining the course of flowing water boundaries were performed for the Polish data.

SPATIAL DATA SPECIFYING THE COURSE OF BOUNDARIES OF FLOWING WATERS IN POLAND

The course of boundaries of land occupied by flowing waters in Poland is illustrated on cadastral maps. The boundary of flowing water should be the same as the shoreline. All spatial data defining the course of boundaries of such land in Poland are entered into the register of land and buildings. When assessing the quality of spatial data describing the course of the shoreline, the quality of cadastral data should also be assessed. This varies in Poland due to historical conditions. Historical conditions meant that during the partitions (1795–1918), when Poland no longer existed on the map of Europe, various cadastral systems functioned there, i.e. the Prussian and Austrian cadastres (Fedorowski, 1974; Wilkowski, 2005; Mika, 2010). In the territories annexed by Russia, a cadastral system did not exist as there was no full map coverage.

After Poland had regained independence in 1918, several attempts were made to unify the cadastral system throughout the country. However, this was only possible after the Second World

War (Fedorowski, 1974). Currently, in Poland, there is a uniform cadastral system for the whole country, called the register of land and buildings. The register of land and buildings (the real estate cadastre) is an information system that ensures the capturing, updating and making available of information on land, buildings and premises, their owners and entities owning or managing these lands, buildings or premises, in a manner that is uniform for the entire country (PGIK Act, 2018). In the register of land and buildings, the basic geodetic unit is the cadastral parcel. A cadastral parcel is a continuous area of land, legally homogeneous, separated from the surrounding area by boundary lines (Rozporządzenie, 2001). In addition to the boundary, the parcel also has a unique registration number and area.

The methods of establishing the register of land and buildings in Poland varied depending on the location. When establishing land records, all the materials defining the boundaries of cadastral parcels, including those established during the partitions, had to be used. Due to the fact that these materials were derived from various cadastral systems, the methods of establishing land records in individual areas of Poland were not uniform. According to Wilkowski (2005), the analysis of the methods of measuring parcel boundaries used during the establishment of land records carried out by the Head Office of Geodesy and Cartography (Pol. Główny Urząd Geodezji i Kartografii) – public authority, revealed that:

– 34.5% of cadastral districts had boundaries measured by direct survey methods,
– 23.5% of cadastral districts had boundaries determined by photogrammetric methods with the use of photomaps,
– 42.0% of cadastral districts had boundaries determined based on various source documents, including cadastral surveys.

The direct survey method consisted of measuring land-use boundaries in the field by farmers using surveying methods. The photogrammetric method consisted of determining the boundaries of agricultural land with the use of aerial photos, which showed clear traces of use. The method, using source documentation, consisted of determining the limits of possession on the ground based on cadastral maps developed mainly in the nineteenth century. The establishment of uniform land records in Poland was completed in the 1980s. Since the 1990s, cadastral data specifying the course of boundaries has been systematically updated. Currently, when updating the cadastral survey, surveying and photogrammetric methods using aerial photographs are used to measure boundaries of cadastral parcels.

A special example of a boundary that naturally delimits property rights is a shoreline. Pursuant to a 2001 ministerial regulation on the register of land and buildings (Rozporządzenie, 2001), the course of the shoreline defined in the field should be the same as the boundary of the cadastral parcel. All data determining the shoreline can be found in the register of land and buildings. The information on the shoreline will primarily include spatial data defining its course (plane and vertical coordinates of the turning points of the watercourse boundary, width and length of the watercourse bed), as well as descriptive data. The descriptive data includes: the method of determining the course of the shoreline (i.e. the clear edge of the shore, boundary of permanent grass growth, average water level), the legal status of the land under water, the body managing the watercourse or the manner of development of the land adjacent to the watercourse. The quality of the information on the shoreline will be influenced by the quality of the data defining it, mainly spatial data and, to a lesser extent, descriptive data. The cadastral data will constitute the basis for the description of the shoreline. It can therefore be concluded that the register of land and buildings will be the reference set for the shoreline information, and the quality level of the cadastral data will have a significant influence and directly translate into the quality of the shoreline description.

GENERAL INFORMATIONS

The analyses were carried out in the areas of the former Prussian, Austrian and Russian partitioned sectors in order to take into account the historical aspect of the research. The works covered four provinces: Lesser Poland (Pol.: Małopolskie) – former Austrian sector, Silesia (Pol.: Śląsk) – former Austrian sector, Świętokrzyskie – former Russian sector and Warmia Masuria (Pol.: Warmińsko-Mazurskie) – former Prussian sector (Fig. 2). The analyses were carried out in 30 cadastral districts located in 15 communes within five counties. The works covered the courses of the shorelines of 21 natural watercourses with unregulated channels over a length of approximately 62 km. The total area of the analysis was approximately 1.217 km^2.

The methodology of the research, the purpose of which was to determine the level of quality of spatial (cadastral) data defining the course of the shoreline, was divided into two stages. In the first stage, research periods were selected in order to identify characteristic methods of establishing a cadastre for a given region of Poland and the time of origin of spatial data. Secondly, with the use of cadastral data defining the course of the shoreline and the orthophotomap defining the actual and current extent of water in the field, the level of data quality was estimated. Then, based on the estimated values of the factors used to assess the quality of the data (using Equations 1–4), and a general model of the criteria for the hierarchy of urgency of updating work performance and a sequence scheme for updating work performance for a given area was developed in accordance with the general assumptions of the methodology presented in Figure 1.

DATA USED

In order to select the research periods, an analysis was made of the materials defining the course of the boundaries specified in the National Geodetic and Cartographic Documentation Centre (Pol. Centralny Ośrodek Dokumentacji Geodezyjnej i Kartograficznej). The National Geodetic and Cartographic Documentation Centre in Poland is a collection of all geodetic and cartographic materials containing spatial data describing the boundaries contained in the register of land and buildings, and thus also data on the boundaries of flowing waters. Spatial data describing the course of water boundaries was analysed in terms of the time of their origin and the surveying method of their capture. The performed analysis allowed us to distinguish the methods of land surveying and the method of preparing a land records survey in different years. Thus, it was possible to select research periods that would take into account all the methods of creating a land records survey in Poland. Based on the conducted analysis and taking into account the fact that changes in the course of the shoreline should be studied over periods longer than seven years (Mika, Siejka and Leń, 2016), a division into five research periods was made. The research periods are listed below:

Fig. 2. Location of the analysed area: source: own elaboration with use GIS analyses

- period I – before 1955
- period II – 1956–1968
- period III – 1967–1981
- period IV – 1982–1996
  - period IVa – the 1980s
  - period IVb – the 1990s
- period V – 1997–2020
  - period Va – 1997–2014
  - period Vb – 2015–2020

METHODOLOGY OF ANALYSES USED TO ESTIMATE THE LEVEL OF QUALITY OF CADASTRAL DATA DEFINING THE COURSE OF THE SHORELINE

After the research periods presented in chapter: “Data used” had been chosen, the test areas were selected. In order to check whether the old cadastral systems influence the quality of today’s cadastral data defining the shoreline, agricultural land located in the areas of the former Austrian, Russian and Prussian partitioned sectors were selected to carry out the analyses. The subject of the analyses were natural watercourses with unregulated channels, which change the course of the shoreline much more frequently than those with regulated channels.

In order to estimate the quality of data determining the course of the water boundary entered into the land records, a cadastral map and an orthophotomap were used, illustrating the current course of the shoreline in the field. The orthophotomap was obtained from the National Geodetic and Cartographic Documentation Centre in Poland. For the purpose of the analyses, the range of the water table visible on the orthophotomap was considered the “current course of the watercourse boundary”. In order to determine the current course of the water boundary in the field, vectorisation was performed, i.e. the cartometric measurement of the water table boundary visible on the orthophotomap. An orthophotomap with a 0.25 m Ground Sample Distance was used. In order to eliminate the subjective factor during the vectorisation of the water boundary on the orthophotomap, edge detection with the Canny algorithm was used. As was demonstrated in research carried out by Mączyńska and Kwartnik-Pruc (2018), this algorithm could be used to determine the range of the water table visible on the orthophotomap. The analyses were performed with the use of GIS tools in Matlab, QGIS and ArcGis.

In order to determine the current boundary of the watercourse, the edge of the water table visible on the orthophotomap was detected. Detection was performed in an application created using Matlab software. Edge detection with the Canny algorithm was used. Then, the edges generated by the algorithm were vectorised using QGIS software. As a result of the vectorisation, spatial polygons were created defining the range of the water surface in the field. Having created spatial polygons with the use of ArcGis software, the area of land occupied by water in vectorised boundaries was calculated based on the orthophotomap. Then, the cadastral map was vectorised in order to define the course of the watercourse boundary illustrated on the cadastral map. After creating spatial polygons using ArcGis software, the area of the land occupied by the watercourse and entered into the land records survey was calculated. In the next stage of the works with the use of ArcGis software, the area of the land occupied by the watercourse was intersected on the cadastral map and the orthophotomap, thus obtaining the product (the common part) of the area (Fig. 3).

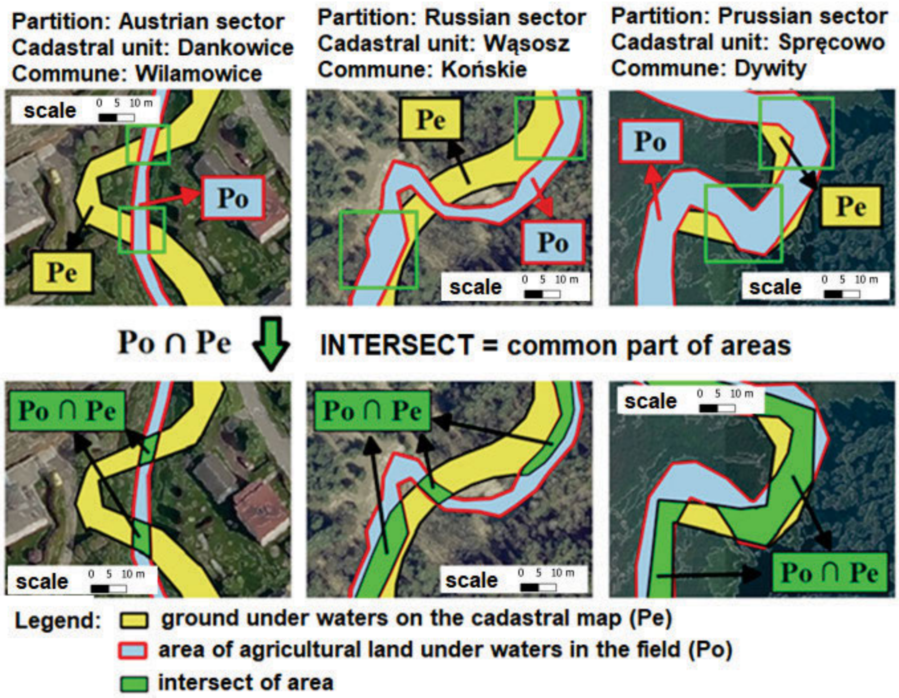

Fig. 3. Determining the product of land area occupied by a watercourse based on the cadastral map and orthophotomap using ArcGis software; source: own elaboration

The next stage of the work involved the calculation of the values of the factors necessary to assess the quality of the cadastral data defining the course of the watercourse shoreline (c1), i.e. the degree of data timeliness (%A), the degree of its completeness (C_{cz}) and the degree of redundancy (CE_{cz}), using Equations (4), (2) and (3). Equations (2) and (3) are a modification of the Equations presented by Nowak Da Costa (2016) that were previously adjusted to the data defining the course of the watercourse boundary. Equation (4), which describes the degree of spatial data timeliness, is an original solution to the problem.

$$Pn_I = P_e - P_I \tag{1}$$

where: Pn_I = area of land under water that is inconsistent on the orthophotomap and on cadastral map, P_I = product of intersecting (consistent) areas occupied by the watercourse on the orthophotomap and cadastral map, P_e = area of land occupied by the watercourse as determined by the cadastral map.

$$C_{Cz} = \frac{2\sum P_I}{\sum P_o + \sum P_e} 100\% \tag{2}$$

where: P_o = area of land occupied by the watercourse as determined by the orthophotomap.

$$CE_{Cz} = \frac{2\sum Pn_I}{\sum P_o + \sum P_e} 100\% \tag{3}$$

$$\%A = \frac{P_I}{P_e} 100\% \tag{4}$$

where: %A = estimated timeliness of the watercourse shoreline entered into land records.

Having performed the analyses for one natural watercourse (c1) with an unregulated channel, the tests were repeated for the second watercourse (c2). After selecting the second watercourse (c2), an analogous calculation procedure was carried out and the values of the factors (%A, C_{cz}, CE_{cz}) used to assess the quality of the data were obtained. Then, the average value of each factor (%Aavg, C_{cz}avg, CE_{cz}avg) used to assess the quality of the cadastral data describing the course of the shoreline in a given research period was determined. The mean value was calculated as the arithmetic mean of the values of the factors (%A, C_{cz}, CE_{cz}) determined for both watercourses (c1 and c2).

METHODOLOGY OF DEVELOPING A MODEL OF THE CRITERIA FOR THE HIERARCHY OF URGENCY OF UPDATING WORK PERFORMANCE

Having calculated the mean values of the estimated factors (%Aavg, C_{cz}avg, CE_{cz}avg) used to assess the quality of spatial data in each research period according to Equations presented in chapter "Methodology of analyses used to estimate the level of quality of cadastral data defining the course of the shoreline", they were analysed in detail in order to select the principal factors (Fig. 1). Their trend of changes in time was, in particular, examined. In accordance with the general assumptions of the methodology presented in the "Introduction" to this research paper and in Figure 1, the following principles were used to select the principal factors:

– if the trend of changes in time for all analysed factors is maintained, the analyses should be simplified to one factor only, e.g. the timeliness factor; the selected factor should be taken as the principal factor and further analysis should be based on only one principal factor; this will allow the amount of work to be reduced without affecting their final result; thanks to this simplification, our work will become more effective;

– if the trend of changes is different for different factors in further analyses, all factors describing the quality of spatial data should be taken into account and treated separately as principal factors.

Having selected the principal factors and based on the estimated values of the principal factors describing the quality of spatial data, a general model of the criteria for the hierarchy of urgency of updating work performance was created in the next stage of the work. The model structure diagram is illustrated in Figure 4. In order to build the model, in the first stage, the spatial data describing the analysed phenomenon was arranged in a hierarchical order, from the lowest quality data to the highest quality data. The structured data in ascending order created the model of the criteria for the hierarchy of urgency (Fig. 4). Then, the model of the order of updating work performance was created, making the order of updating work performance dependent on data quality. In order to create the model, the principle of assigning the order of updating work performance was applied in the same order as the criteria for the hierarchy of urgency was created (Fig. 4). For example, if the hierarchically ordered data in the model of the criteria for the hierarchy of urgency was the lowest number (1), then it was also given number 1 in the model of the order of updating work performance, which means that the lowest quality data will be updated first. Figure 4 illustrates the construction diagrams of both models.

necessary to assess the quality of data defining the boundaries of watercourses (Tab. 1), were calculated. In the next stage of the work, the average values of each factor (%*A*avg, C_{cz}avg, CE_{cz}avg) in a given research period were calculated (Tab. 1).

TREND OF CHANGES IN TIME OF FACTORS USED TO ASSESS THE QUALITY OF SPATIAL DATA DESCRIBING THE COURSE OF WATER BOUNDARIES

The analysis of the factors used to assess the quality of the cadastral data defining the course of the shoreline is presented below. It distinguishes between the methods, time and area (partitioned sector) of the data source.

"Timeliness" factor

Figure 5 illustrates the mean value of the %Aavg factor describing the timeliness of the cadastral data defining the course of the watercourse boundaries illustrated on the cadastral map. Figure 5 demonstrates that the time when the cadastral data determining the course of the shoreline was captured affects their timeliness. The older the survey of the watercourse boundaries is, the worse the timeliness of the data contained in the records, i.e. the course of the watercourse boundaries currently shown in the records is less similar to the actual course in the field. Figure 5 also demonstrates that in the areas of the former Austrian and Russian

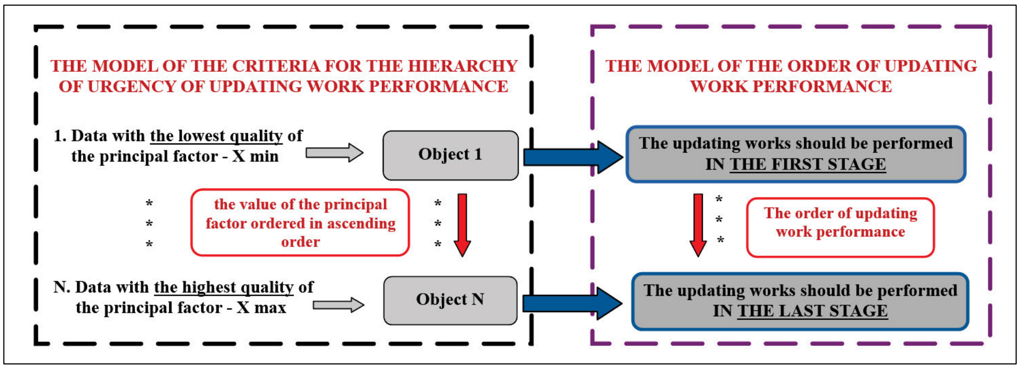

Fig. 4. Structure diagram of the model of the criteria for the hierarchy of urgency of updating work performance; source: own elaboration

RESULTS

GENERAL INFORMATIONS

This chapter presents results of all analyses. In order to estimate the quality of spatial data in accordance with the methodology presented in chapter "Materials and methods", GIS spatial analyses were initiated. In the first stage, the following were determined: the area of the land occupied by the watercourse within the boundaries contained in the cadastre (P_e); the surface of the land occupied by the watercourse within the water table illustrated on the orthophotomap (P_o); and the products of these areas (P_I). Then, based on Equations (2), (3) and (4), in accordance with the methodology described in chapter "Methodology of analyses used to estimate the level of quality of cadastral data defining the course of the shoreline", the level of data timeliness (%*A*), its completeness (C_{cz}) and redundancy (CE_{cz}),

partitioned sectors, the timeliness of the data defining the water boundaries contained in the land records from period III to this day is similar. In the first two research periods, i.e. I–II, there are discrepancies that result from different methods of establishing land records in these former partitioned sectors. The high value of the index in the first research period in the territory of the Russian sector is a local phenomenon. It results from other measurement techniques that lead to the establishment of a cadaster in that area.

"Completeness" factor

Figure 6 presents the mean value of the C_{cz}avg factor describing the degree of completeness of the cadastral data defining the course of the watercourse boundaries illustrated on the cadastral map. The degree of completeness of the data demonstrates the degree of similarity between two spatial data sets, and in this case it determines the degree of similarity between the area occupied

Table 1. Values of calculated factors determining the level of quality of data describing the course of water boundaries

Partition	Time period[1]	Analysed cadastral district (location)	Method of establishing land records	Time of establishing land records	Watercourse length (km)	%A	C_{cz}	CE_{cz}
							%	
Austrian sector	I	Bestwina	derivative of cadastral map	time of partitions	1.0	28	36	94
		Czaniec			3.2	32	47	100
		Dankowice			1.0	32	43	92
	II	Szczyrk	field survey	1960s	1.3	42	58	80
	III	Wilamowice		1970s	1.5	44	60	77
	IVa	Międzyrzecze Dolne		1980s	1.5	50	67	66
		Międzyrzecze Górne			1.3	48	64	70
	IVb	Porąbka		1990s	0.6	64	77	43
		Pisarzowice			1.0	62	76	47
	Va	Mazańcowice		2007	1.9	71	82	34
	Vb	Kościelisko	photogrammetric survey	2014–2015	2.8	85	90	15
		Białka Tatrzańska			1.5	87	91	13
Russian sector	I	Matyniów	field survey	interwar period	0.6	55	68	55
		Błaszków			2.0	56	67	54
	II	Małachów	photogrammetric survey	1967–1968	3.5	26	40	112
		Janów			2.5	33	42	84
	III	Przybyszowy	field survey	1980	3.0	38	54	88
		Ruda Białaczowska		1981	4.0	41	53	76
	IVa	Sąporków		1983	3.00	56	66	52
		Duraczów		1988	3.0	53	55	50
	IVb	Końskie obr. 04		1994	0.8	63	77	45
		Końskie obr. 05			1.1	61	76	49
	Va	Młotkowice		1997	1.5	70	70	30
	Vb	Wojciechów	photogrammetric survey	2018	1.4	83	89	18
		Cudzynowice			0.8	83	90	19
Prussian sector	II	Brąswałd	field survey	1963	3.0	72	84	33
		Bukwałd		1964	1.5	73	74	27
	III	Cerkiewnik		1976	5.0	79	85	23
		Spręcowo		1977	5.0	82	81	18
	IVa	Zalbki		1983	1.5	93	94	7

[1] Duration of periods I–Vb as in p. 5.
Source: own study.

by water within the boundaries illustrated on the cadastral map and the actual area occupied by water within the boundaries illustrated on the orthophotomap. The degree of completeness (similarity) of the cadastral data presented in Figure 6 is similar to the degree of timeliness of the data presented in Figure 5. The difference is that in Figure 6 one can observe greater differences in the values of the factors obtained for the former Austrian and Russian sectors. However, the main trend of changes in time remains the same, i.e. the older the cadastral data defining the course of the watercourse boundaries, the less complete it is. This means a smaller degree of similarity between the water boundary contained in the records and the actual boundary illustrated on the orthophotomap. The high value of the index in the first research period in the territory of the Russian sector is a local phenomenon. It results from other measurement techniques that lead to the establishment of a cadaster in that area.

"Redundancy" factor

Figure 7 presents the mean value of the CE_{cz}avg factor describing the degree of redundancy of the cadastral data defining the course of the watercourse boundaries illustrated on the cadastral map. The degree of redundancy is used to define the completeness element of spatial data quality description. Thus, it complements the previously calculated degree of similarity between the course

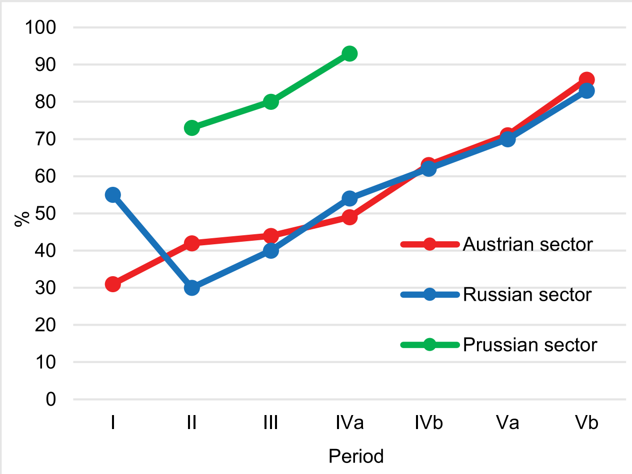

Fig. 5. Degree of timeliness of cadastral data defining the course of the shoreline in individual formerly partitioned sectors; source: own study

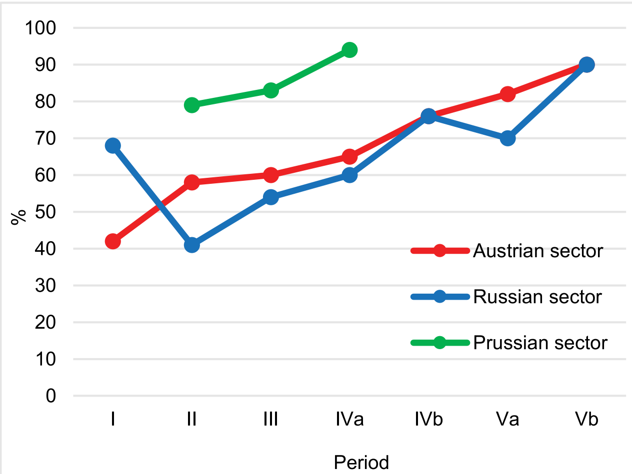

Fig. 6. Degree of completeness of cadastral data defining the course of shorelines in individual formerly partitioned sectors; source: own study

of the watercourse boundary contained in the records and the actual water boundary illustrated on the orthophotomap. Figure 7 demonstrates that the degree of data redundancy, as well as the two previous factors (timeliness, completeness), is influenced by the time the cadastral data was captured. The degree of redundancy decreases as the data becomes more up-to-date. The low value of the index in the first research period in the territory of the Russian sector is a local phenomenon. It results from other measurement techniques that lead to the establishment of a cadaster in that area.

MODEL OF THE CRITERIA FOR THE HIERARCHY OF URGENCY OF UPDATING WORK PERFORMANCE AND ORDER OF UPDATING WORK PERFORMANCE

In the next stage of the work, having analysed the trend of changes in time of all the factors in question, the principal factors were selected. Based on the diagrams illustrated in Figures 5–7, it was found that after considering all the factors influencing the data quality, i.e. the method, time and area of origin of the cadastral data defining the course of water boundaries, there was a clear trend of changes in time in the factors characterising the

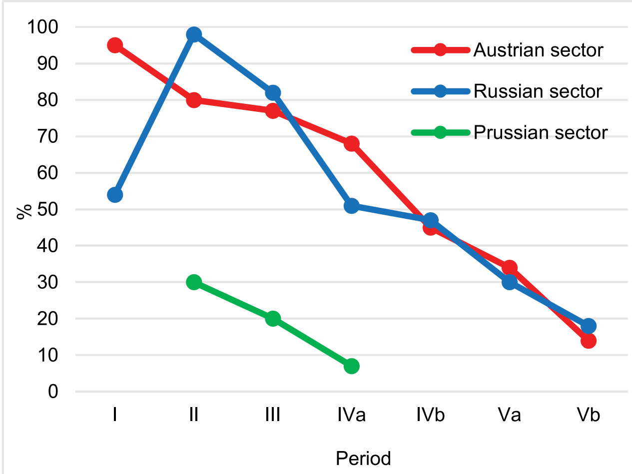

Fig. 7. Degree of redundancy of cadastral data defining the course of shorelines in individual formerly partitioned sectors; source: own study

data quality. The general trend of changes was maintained for all factors, so the analyses could be simplified to one principal factor. The timeliness of the data was chosen as the principal factor (%*A*avg). The development of the criteria for the urgency of the performance of updating works related to the performance of surveys to define the course of the shoreline was based mainly on the analysis of the factor determining the degree of data timeliness (%*A*avg). The trend of changes in the remaining factors for quality assessment analysed in chapter "Trend of changes in time of factors used to assess the quality of spatial data describing the course of water boundaries" (the degree of completeness and the degree of redundancy of data) was consistent with the trend of changes in the timeliness factor (%*A*avg) and therefore, without losses for the results, only one factor was analysed.

Due to the fact that no analyses were performed in the former Prussian sector in period I, the value of the timeliness factor (%*A*avg) was estimated there based on the remaining values in other research periods, maintaining the trend of changes in time. The value of the factor (%*A*avg) was estimated at the level of 66% (Fig. 8).

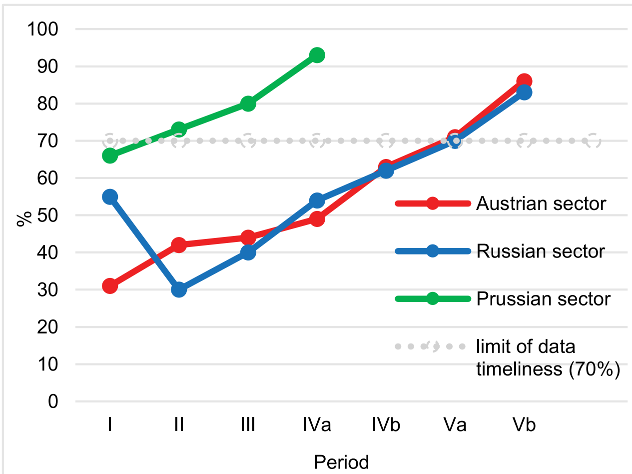

Fig. 8. Estimated degree of timeliness of cadastral data used to select criteria for the hierarchy of urgency of updating work performance; source: own study

Only those areas where the level of timeliness of the cadastral data describing the course of the shoreline was less than 70% were indicated for the updating works. Due to the continuous changes of the shoreline in time, the remaining areas were considered timely (Fig. 8). Based on the estimated values presented in Figure 8, a general model of the urgency of updating work performance related to the performance of surveys of natural watercourses with unregulated channels was created, taking into account the area, methods and time of the capture of the cadastral data. To develop the order of updating work performance for the selected area, in the first stage of the works, the time of origin of the cadastral data defining the course of the shoreline was assigned to the appropriate research period (I–Vb) in accordance with the division presented in chapter "Material and methods". Secondly, based on the location of the test area, i.e. according to the former partition, and the model of the criteria for urgency of updating work performance, a model of the order of updating work performance was created (Tab. 2). Then, for selected test areas located in Poland, sample models were developed which, for better visualisation, are illustrated in Figures 9 and 10.

In order to create a model, it is necessary to capture information about the time of the data capture defining the water boundaries (Figs. 9a and 10a). Then, using Table 2 (which specifies the order of work performance), the order of updating work performance for the relevant period of data capture should be assigned. This makes it possible to identify areas where updating works should be performed first (Figs. 9b and 10b).

In Figures 9 and 10, the areas where the updating works should be performed first are marked in a darker colour. On the other hand, the areas marked in white are those for which there is no need to carry out updating works because the data timeliness there exceeds 70%.

Table 2. Order of updating work performance for shorelines in areas of former partitioned sectors

Time when cadastral data defining course of water boundary was captured	Order of updating work performance in territories of former partitioned sector		
	Austrian	Russian	Prussian
I (before 1955)	update in stage I	update in stage IV	update in stage I
II (1956–1968)	update in stage II	update in stage I	no update required
III (1969–1981)	update in stage III	update in stage II	no update required
IVa (1982–1990)	update in stage IV	update in stage III	no update required
IVb (1991–1996)	update in stage V	update in stage V	no update required
Va (1997–2014)	no update required	no update required	no update required
Vb (after 2015)	no update required	no update required	no update required

Source: own study.

DISCUSSION

The performed analyses have demonstrated that the time of origin of the cadastral data defining the course of water boundaries has a significant effect on their quality. Having analysed the factors (timeliness, completeness, redundancy) used to assess the quality of cadastral data (chapter "Comparison and analysis of the trend of changes in time of factors used to assess the quality of spatial data describing the course of water boundaries"), their clear trend of changes in time was noticed. The conducted research has proved that after considering the methods, time and area of origin of cadastral data describing the course of water boundaries in the analyses, there is a clear trend of changes in time in the factors characterising the quality of cadastral data describing the course of the shoreline. Thus, it is possible to specify the estimated degree of quality of cadastral data defining the course of watercourse boundaries only based on the information about the method, time and area of data origin in the context of the former partition sector. Therefore, it is also possible to develop criteria for the urgency of updating work performance related to surveying the course of the shoreline in the field.

The analyses have demonstrated that, when analysing spatial data, it is very important to take account of all the elements influencing its quality. The time of origin of spatial data should not be the only factors to rely on and consider. Analyses of cadastral data defining the course of water boundaries in Poland have demonstrated that the quality is also influenced by the method of data origin, e.g. field surveys or the photogrammetric method. The assumption that only the time of origin affects the quality of data is incorrect. Considering only the time of origin of the data in the analyses would produce false results. Similarly, neglecting historical conditions in the analyses would also have a negative effect on the results.

The choice of representative objects for research in each research period appears to be essential as well due to the fact that all analyses are based on them.

The selection of data for analyses is a key element of all research studies. The analyses using GIS tools do not pose any problem. The methodology presented in the paper is based on simple but effective assumptions. However, the choice of: periods, objects and factors influencing data quality can be problematic. The selection of data for analyses and factors describing spatial data requires extensive knowledge and experience in analysing a given problem or phenomenon. This forms the basis for further analysis.

The research has also demonstrated that in order to increase the efficiency of work, the smallest number of principal factors should be selected for the final analysis. Limiting the analyses to

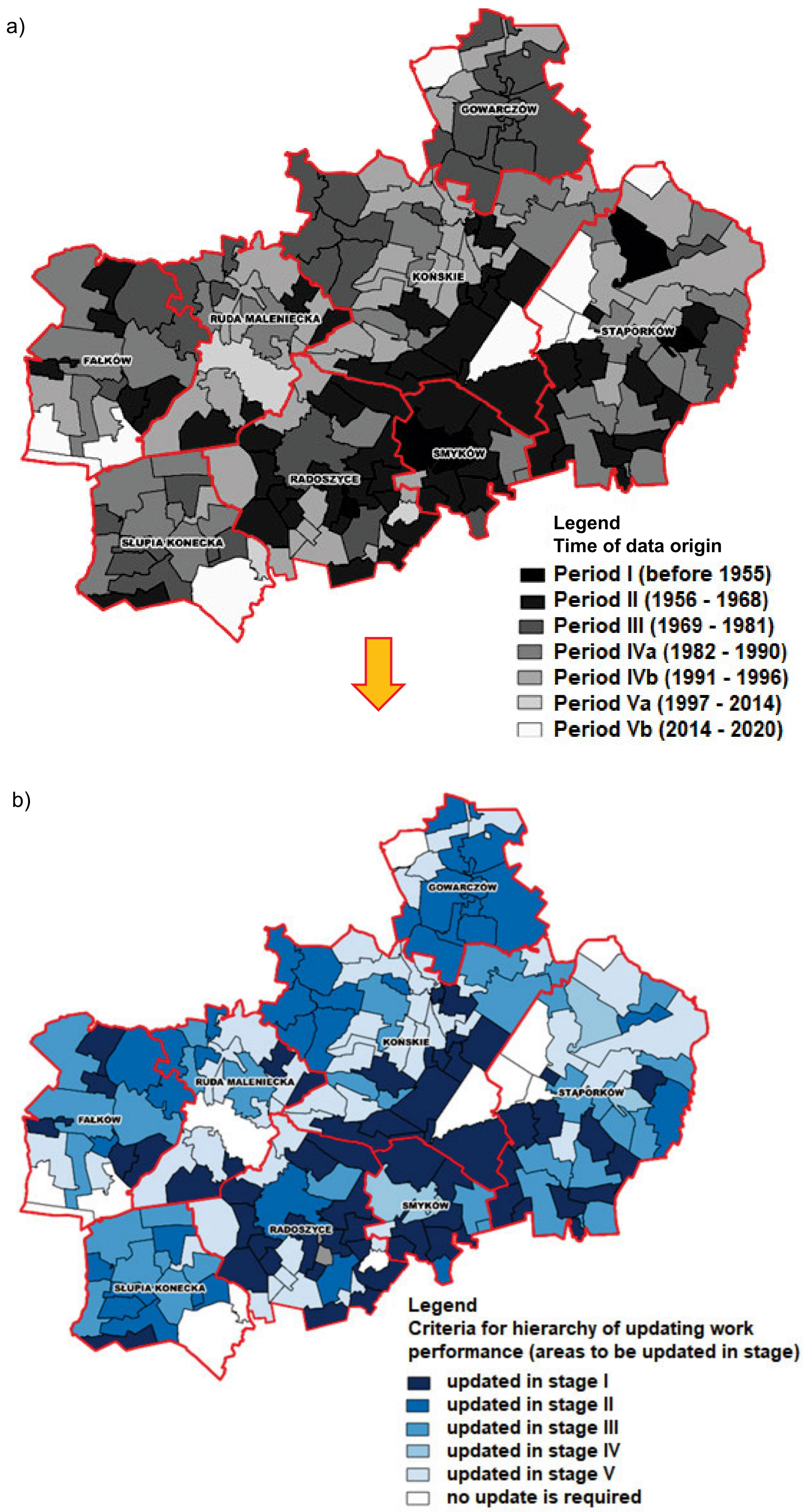

Fig. 9. Scheme of the model for creating urgency criteria for updating work performance for Końskie county (former Russian sector): a) time of data origin, b) criteria for hierarchy of updating work performance; source: own study

a smaller number of factors does not affect the final result, yet it definitely reduces the amount of work.

The general scheme of the criteria for the hierarchy of urgency of updating work performance created above may be applied to a selected test area in Poland. It makes it possible to develop criteria defining the order in which surveys of the shoreline for any area of Poland are to be performed. In order to develop a sequence scheme for updating work performance for a selected test area, the only thing that is required is information about the time of the original cadastral data defining the course of boundaries of cadastral parcels and the location of the test area (to identify the former partitioned sector).

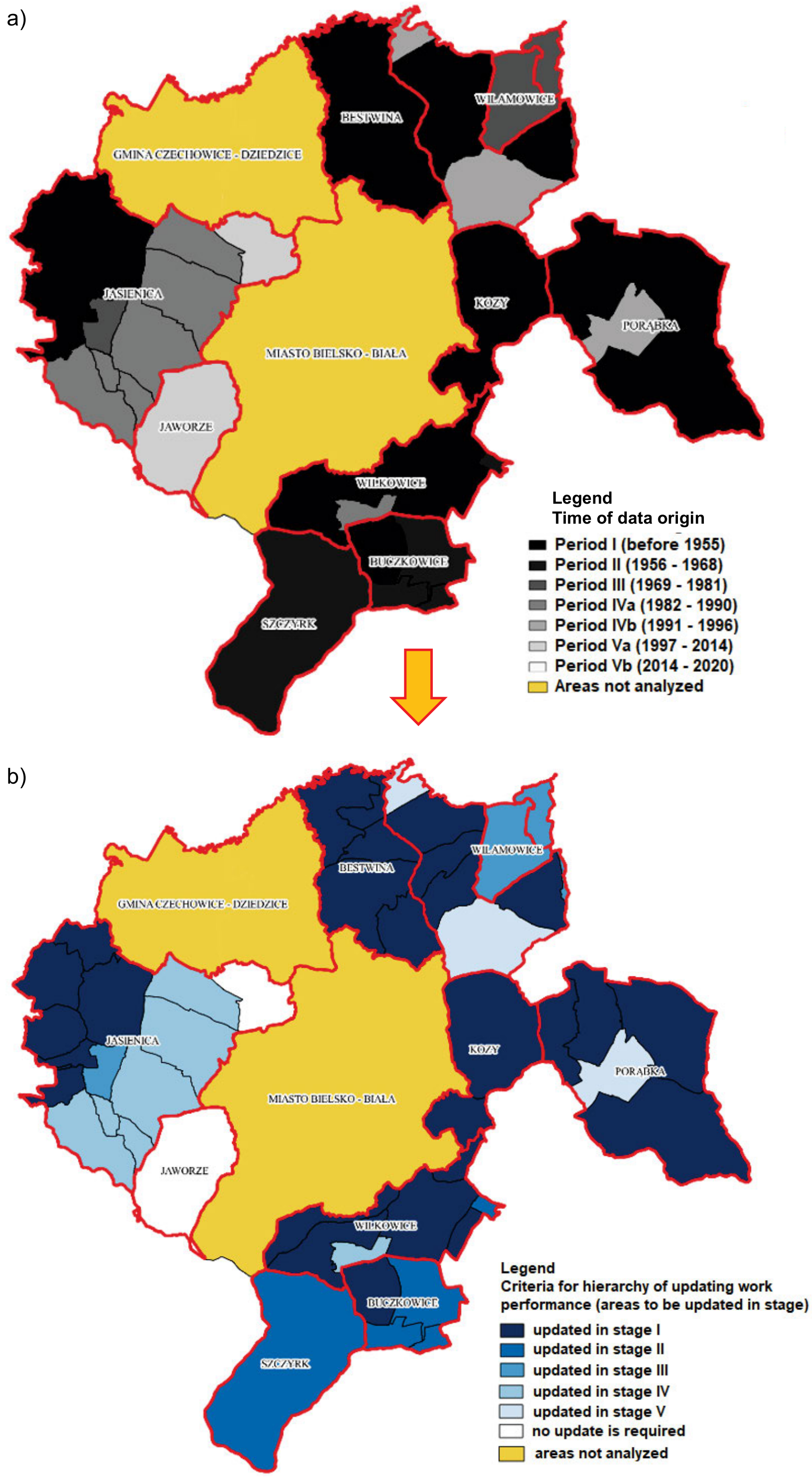

Fig. 10. Scheme of the model for creating urgency criteria for updating work performance for Bielsko county (former Austrian sector); a) time of data origin, b) criteria for hierarchy of updating work performance; source: own study

CONCLUSIONS

The development of hierarchy criteria for performing updating surveys of the course of the shoreline of natural watercourses with unregulated channels has numerous advantages. According to the authors of this research paper, one of the most important advantages is that the works can be carried out comprehensively, and not on a point-by-point basis for single cadastral parcels. This will enable the gradual data to be updated for individual cadastral districts and therefore the regulation of the legal status of all agricultural properties directly adjacent to the waters within a given cadastral district. After the legal status of agricultural land has been regulated, it will be possible to trade in land again. The land turnover will increase the area of farms and, consequently, the efficiency and productivity of individual farms in Poland. In addition, the correct determination of water boundaries will also support the natural water resource management process. This is due to the fact that it forms the basis for the effective management of water resources, which should be based on sustainable development.

The original method of data quality assessment presented in this research paper and the authors' own method of creating the criteria for the hierarchy of urgency of updating work performance are versatile and can be used for all kinds of spatial data which take the form of closed polygons. The areas must be closed, because only then is it possible to calculate their areas. Calculating the area is necessary to estimate the quality of spatial data, from which a general urgency model can be built to suit any given data.

The presented methods can be successfully used for spatial data describing any phenomenon or problem, the solution of which requires the assessment of the quality or timeliness of the data describing it.

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