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The need for renewal of the cadastral maps on the territory of Vojvodina, Republic of Serbia

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Abstract

The objective of this research is to establish a ranking of five cadastral municipalities within the administrative municipality of Pancevo in order to determine the priority for the renewal of cadastral maps. To facilitate ranking of cadastral municipalities, the VIKOR method, a multi-criteria optimization technique, was employed. For the optimization of cadastral map renewal in the study area, a list of eight criterion functions (f_i), six sub-criteria (k_{ij}), and four different combinations of weights (ω_i) were adopted to express the varying relative importance of criterion functions. The results obtained, in the form of ranking lists for each combination of weights, facilitated the development of a hierarchy indicating the urgency for initiating cadastral map renewal works. Based on the results, the cadastral municipality of Dolovo is recommended as the optimal compromise solution according to the first combination of weight values. It holds the top position on the compromise ranking list, enjoying a 64.8% advantage over the alternative in second place. For the second combination of weight values, the proposal consists of two alternatives: Dolovo and Omoljica. Dolovo occupies the top position on the compromise ranking list, with a 17.8% advantage over Omoljica in second place. Furthermore, Dolovo also secures the top position on the QR and QS ranking lists, thus representing the optimal compromise solution. The proposal for the third combination of weight values suggests a compromise between Pancevo and Dolovo. Pancevo holds the top position on the compromise ranking list, enjoying a 6.1% advantage over Dolovo in second place. However, Dolovo, with a 35.5% advantage over the alternative in third place, satisfies the condition of a significant advantage. In the fourth combination, Dolovo exhibits a 44.3% advantage over the second alternative.

1. Introduction

The graphical geodetic survey of the area covered by today's Vojvodina was carried out during the time of the Austro-Hungarian monarchy, at the end of the 19th and the beginning of the 20th century. The maps were produced in a stereographic projection (the old Austro-Hungarian survey) [1] at the scales R = 1:1440 for cities and R = 1:2880 for villages and suburbs [2], on a base that was either hammer paper or map paper backed with linen. In addition to the cadastral maps, which were preserved to this day, there are lists of parcels with areas expressed in the hvat measurement system [3]. In the hvat measurement system, the dimensions of the parcels are expressed in a unit called hvat. The hvat is equal to 1.8965m, which corresponds to the Austrian unit of measure for the length called klafter, which also had a value of 1.8965m. It can be said that hvat represents Vojvodina's version of the Viennese klafter [4].

There are cadastral (or cadastre) municipalities in Serbia, and therefore in Vojvodina as well, which represent cadastral subdivisions of administrative municipalities [5]. For some cadastral municipalities, so-called "preliminary drafts" or "survey bases", which represent cadastral field sheets from the time of the Austro-Hungarian monarchy, with data expressed also in the hvat measurement system, are preserved [6].

As for ownership data, in all cadastral municipalities in Vojvodina there was a land book from that time, which took over the data of the graphical survey and maintained it with all changes until the new real estate cadastre records came into force.

After the end of the Second World War, the first numerical geodetic surveys of cadastral municipalities in

the territory of Serbia and Vojvodina were carried out [4]. The purpose of the numerical survey was to obtain the first numerical data on the land and the buildings on it in order to form a completely new record called the land cadastre.

However, the overall rapid development in all areas of life, work and business, and especially the development of spatial information technologies and sustainability theory [7], has caused the need for a much larger amount of spatial information which society and science may need [8]. For this reason, the existing records of the land cadastre become insufficient, so a completely new record in the form of a real estate cadastre is created on its basis. The holder of the project on the creation of new real estate cadastre records on the territory of the Republic of Serbia was the Republic Geodetic Authority as the only state agency entrusted with tasks in the field of creation and maintenance of the real estate cadastre [2].

2. Real estate cadastre in Serbia

Works on the establishment of the real estate cadastre began in 1988 and was completed in 2011. The real estate cadastre was created by unifying data on real estate contained in two separate registers - the land cadastre and the land book. The land cadastre was the register containing geometric data on parcels and buildings, while the land book was a register of ownership of parcels and buildings.

Access to alphanumeric data on real estate is provided to all users through the internet application eKATASTAR (in English: *eCADASTRE*). Besides citizens, the users of eKATASTR are ministries and other state administration bodies, tax authorities, real estate agencies, law offices, geodetic organizations, construction companies, etc.

In addition to this application, the internet portal GeoSrbija is also available, which represents a database of all geospatial data of the Republic of Serbia that can be used by citizens, state authorities, the economy and the public sector. Through this internet portal, it is possible to access data on registered real estate at any time.

In the process of establishing the real estate cadastre, one of the most important tasks is the renewal of the existing cadastral maps, which aims to create new digital cadastral maps. Besides the Republic Geodetic Authority, geodetic organizations also participate in the creation of digital cadastral maps.

The legal framework for the introduction and establishment of the real estate cadastre is defined by the Law on State Survey and Cadastre adopted in 2009.

By adopting a decision on the confirmation of the real estate cadastre for a certain cadastral municipality, the land cadastre and the land book ceased to be valid, by which the procedure of maintaining a new real estate cadastre register started.

From 1992 to 2002, works on maintaining cadastral records was performed exclusively by the Republic Geodetic Authority through its services in cities and administrative municipalities, and from 2002, when the changes to the Law on State Survey and Cadastre were adopted, registered private geodetic organizations participate in performing field works related to maintaining geodetic survey.

3. Current state of the cadastral maps

Although the Republic of Serbia adopted real estate cadastre in 2011 [2], in all cadastral municipalities on the territory of Vojvodina, in which land consolidation was not carried out, cadastral maps of the "old" graphical survey are still in use. In those areas, the preservation and possibility of using the “old” cadastral maps is at different levels. Thus, there are cadastral maps that are extremely well preserved, but at the same time there are also those that are completely or partially unusable. The reason for this is certainly the many years in which these maps were used, the lifetime of the foundation on which they were created, but also the inadequate way of archiving and using them [6].

By analyzing these maps as carriers of certain information about the space, quantitative and qualitative indicators of their content are obtained. When it comes to the quantity, that is, the number of different information contained on the maps, it is a very small number. Namely, these maps show only the borders of the parcels, the numbers of the parcels and the boundaries of residential buildings. The reason for this is that at the time when these maps were created, there was practically no other content on the ground. In addition, the requirements of the users at the time were such that this content of the maps was completely satisfactory [9].

When it comes to the quality of the information provided, data on the boundaries of parcels and buildings are of a graphical type, it is practically a drawing, so usability of such data is very limited. These limitations in use arise in any case when numerical data are required, such as the coordinates of boundary points, detailed points, areas of parcels and objects, and others. True, the cadastral record contains a list of areas, but also from the time of conducting graphical survey [10]. In addition, the parcels and objects shown on the cadastral maps are not described with any other attributes that would affect obtaining better quality information. The example of an “old” cadastral map created on the bases of graphical survey data is shown in Figure 1.

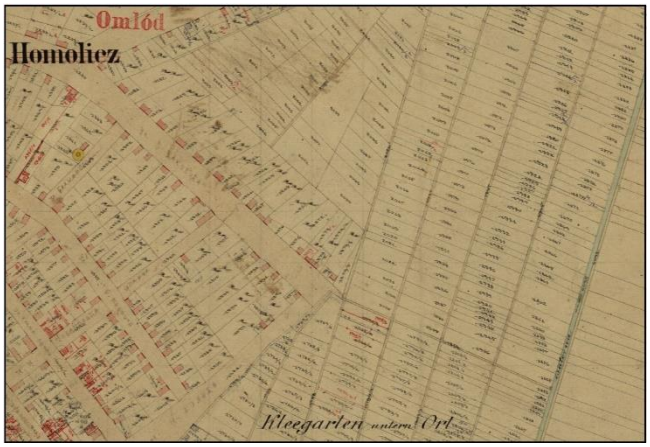

Figure 1. An “old” cadastral map (source: The Republic Geodetic Authority, The Archive Department)

All these facts point to the need for the renewal of the cadastral maps in cadastral municipalities where cadastral maps of graphical survey are in use. The practice in the Republic of Serbia is that in such areas the renewal of cadastral maps is carried out as part of the procedure of land consolidation. The problem with this approach is that land consolidation is a long process, which implementation in the Republic of Serbia takes up to 7 years, and there are also examples of land consolidation that, even after more than 10 years from the beginning, did not result in the renewal of the cadastre and registration of property rights [11]. In [11] is also estimated that with this dynamic, it would take more than 30 years to consolidate about 400,000 hectares, which is only half of the estimated need for land consolidation in Vojvodina.

Contemporary and up-to-date cadastral maps are of great importance in the promotion of sustainable development [12] and the management of the environment [13]. It offers fundamental information regarding parcels, and spatial arrangement [14], thereby enabling the efficient planning and administration of resources. In the context of Vojvodina, where numerous initiatives pertaining to agriculture and environmental preservation are frequently undertaken [15-17], up-to-date cadastral maps serve as a foundation for making well-informed decisions. This is crucial in identifying areas that necessitate special attention in terms of nature conservation, resolution of water-related issues [8], or enhancement of agricultural practices. According to the Rulebook on cadastral surveying, cadastral renewal and geodetic works in the maintenance of the real estate cadastre [18], in areas where a graphical survey is in use and where no geodetic survey renewal was performed, renewal of cadastral maps is carried out on the basis of data obtained by surveying the current situation on the ground, applying either aerial photogrammetry method in the rural areas, or terrestrial methods, using total stations and GNSS technology, in urban areas, and creating a digital cadastral map.

In accordance with the above, the aim of this paper is to rank five cadastral municipalities in the territory of the administrative municipality of Pancevo, in which land consolidation was not carried out, to determine the sequence for carrying out work on the renewal of the cadastral maps. The ranking list was created using VIKOR method, one of the MCOM (the acronym: Multi-Criteria Optimization Methods).

There are many MCOM developed to identify answers to issues resulting from competing preferences among different criteria, encompassing a range of strategies for planning, evaluating, and prioritizing future outcomes, as well as the integration of both objective and subjective criteria into decision processes [19].

As part of the optimization procedure, the cadastral municipalities of Pancevo, Starcevo, Omoljica, Kacarevo and Dolovo present alternative solutions, i.e. alternatives, which boundaries, with numeration of the alternatives, are shown in Figure 2.

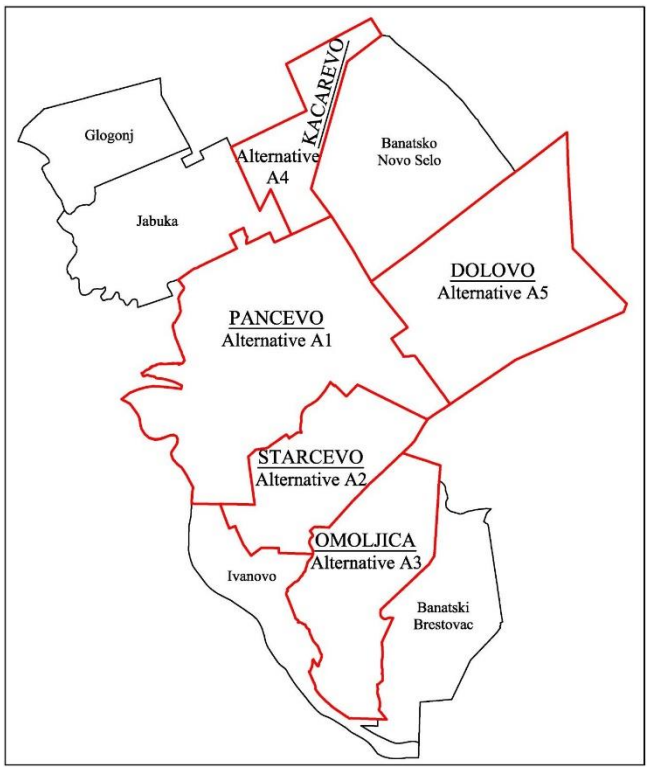

Figure 2. Boundaries of cadastral municipalities, with numeration of the alternatives

Real estate cadastre was established in all municipalities included in the research, but in the municipalities of Omoljica, Kacarevo and Dolovo, graphical survey data is still issued as official data by the cadastre [4]. For the urban cadastral municipality of Pancevo and the rural cadastral municipality of Starcevo, numerical survey data in the metric system of measurements are indeed issued as official data, however, the last geodetic survey in these cadastral municipalities was carried out in the period from 1950 to 1970 and was never renewed.

4. Method

4.1. Defining criterion functions

In multi-criteria optimization procedure, it is crucial to take decision makers' options into account, prioritize them based on their relative significance, and select the option with the highest priority [20]. In this research, respecting the specifics of creating new digital cadastral maps, the provisions of the Law on State Survey and Cadastre [21] and the Rulebook on cadastral surveying, cadastral renewal and geodetic works in the maintenance of the real estate cadastre [18], in which the reasons for the renewal of the cadastral maps are defined, a selection of criterion functions that will objectively show the characteristics of cadastral municipalities as alternative solutions was made. Some of the selected criterion functions for the unit of measure have a monetary unit and can therefore be classified in the group of economic functions. The second group of criterion functions is expressed in technical units of measure, while the third group consists of criterion functions that are unsuitable for quantification and are expressed based on subjective evaluations.

The following list of criterion functions (f_i) and sub-criteria (k_{ij}) was adopted for the multi-criteria optimization of the renewal of cadastral maps in the research area:

- The costs of renewal of the cadastral maps (f_1) - for one cadastral municipality are shown through: the costs of hiring workers of the geodetic organization (k_{11}), the costs of public display of survey data (k_{12}) and the material costs (k_{13}). The cost assessment was done based on the average price of works performed by geodetic organizations.

Within the geodetic organization, one geodetic group is engaged, consisting of one master engineer in geodesy, two applied geodetic engineers and four surveyors. The total costs of hiring workers (k_{11}) are obtained using the Equation 1.

$$k_{11} = c_{11} \cdot (t_1 + t_2) \tag{1}$$

Where c_{11} are costs of hiring employees of the geodetic organization per day, t_1 is time required for the preparation of geodetic-technical and project documentation and t_2 is time required for the realization of the project solution.

The costs of public display of survey data (k_{12}) are incurred by hiring one legal professional and one secretary, who are not permanent employees of the Real Estate Cadastre Service Pancevo. The total costs of public display of survey data (k_{12}) are obtained using the Equation 2.

$$k_{12} = c_{12} \cdot t_3 \tag{2}$$

Where c_{12} are costs of public display of survey data per day and t_3 is time required for the public display of survey data and the acceptance of the new database of digital cadastral maps.

The material costs (k_{13}) are the costs of purchasing office supplies for each real estate deed. Total material costs (k_{13}) are obtained using the Equation 3.

$$k_{13} = c_{13} \cdot p \tag{3}$$

Where c_{13} are material costs per real estate deed and p is number of real estate deeds in a cadastral municipality.

The Equation 4 is used to calculate the total costs of renewal of cadastral maps (f_1), for one cadastral municipality.

$$f_1 = k_{11} + k_{12} + k_{13} \tag{4}$$

- The time required for the renewal of the cadastral maps (f_2) is significantly different for each cadastral municipality because geodetic surveys of cadastral municipalities were carried out in different time periods, with different methods and technologies, and that the degree of preservation of the data of the performed survey, as well as the quality and up-to-dateness in the period of maintenance of land cadastre and real estate cadastre is different. Also of significant influence is the legal obligation imposed by the Regulation on digital geodetic map [22], according to which new digital cadastral maps must be created for each cadastral municipality. Planning of the time required is carried out for each activity in the process of renewal of the cadastral maps separately, with the use of earlier defined geodetic norms. When applying the geodetic norms for calculating the time required to perform individual activities, the specifics of the completed geodetic surveys of the cadastral municipalities for which planning is being carried out must be strictly considered. Set of geodetic regulations called "Geodetic Norms" (in Serbian: Geodetski normativi) adopted in 1990 by the Business Association "Jugogeodet" [23] were used to evaluate the time required for the renewal of the cadastral maps.

Evaluation results are expressed in time units - days, for each activity within the sub-criteria (k_{2j}) through: the creation of geodetic-technical and project documentation (k_{21}), the realization of the project solution (k_{22}) and the public display of survey data and the acceptance of the new database of digital cadastral maps (k_{23}).

The total time required for the renewal of the cadastral maps (f_2), for cadastral municipalities as alternatives, expressed in days, is obtained using the Equation 5.

$$f_2 = k_{21} + k_{22} + k_{23} \tag{5}$$

- The area of the cadastral municipality (f_3) is expressed in technical units of measure, based on which both rural and urban municipalities are equally valued. This criterion function will give priority to the renewal of the cadastral maps in cadastral municipalities with a larger area.
- The number of real estate deeds (f_4) is expressed in the appropriate units of measure. The real estate deed is the basic document related to real estate and the rights to it, registered in the real estate cadastre. The real estate deed, or title deed, is used for a wide variety of needs related to real estate, and it is basically a document that contains information about real estate area, taken from digital cadastral map, type of ownership, and various notes or encumbrances, for example. Basic information that real estate deed contains is what type of real estate it is (house, arable field, apartment, etc.) and who owns it. This criterion function will give priority to the renewal of cadastral maps in cadastral municipalities with a larger number of real estate deeds.
- The average number of changes to real estate during the year (f_5) is obtained by reviewing the data in the cadastral database for each cadastral municipality, which refer to changes to the borders of parcels, changes resulting from the construction, extension or demolition of buildings on the ground, or changes to ownership, all in relation to the state registered in the real estate cadastre. This criterion function is expressed in the appropriate units of measure and will give priority to the renewal of the cadastral maps in cadastral municipalities with a higher average number of changes during the year.
- The coverage of the area of the cadastral municipality by the geodetic network (f_6) is conditioned by the degree of performing related works in the survey procedure and subsequent maintenance of the survey

and real estate cadastre. Based on the analysis of the survey data, an assessment of the coverage of the cadastral municipalities with the geodetic network, expressed in percentages, was made. This criterion function will give priority to the renewal of the cadastral maps in cadastral municipalities with a lower percentage of coverage of the area of the cadastral municipality by geodetic network.

- The assessment of the degree of outdated data presented on the cadastral maps in relation to the current situation on the ground (f_7) is expressed in percentages in this research. A high degree of outdated data is stated in the current legislation as one of the reasons for deciding on the renewal of the cadastral maps. Outdated cadastral maps can lead to a number of serious consequences, including disputes over parcel boundaries, inaccurate planning of urban and rural space, limitation of investment opportunities and negative effects on environmental sustainability. Maintaining up-to-date cadastral maps ensures equitable and efficient land use, which contributes to the long-term sustainable development of the community.
- The possibility of using the existing analogue cadastral maps of graphical survey (f_8) is decreasing every day. Due to the type of base on which they were made, their age, poor archiving conditions and improper use, these maps are either in very poor condition or was destroyed and cannot be used for further survey maintenance and establishing of changes to real estate. The assessment of the possibility of using the existing analogue cadastral maps is expressed in grades, ranging from 1 to 5.

The list of criterion functions and sub-criteria, adopted for the research, are shown in Table 1.

The results of the evaluation of cadastral municipalities as alternative solutions in the procedure of multi-criteria ranking, performed according to each criterion function (fi) based on economic indicators, geodetic norms, cadastral data and free assessment, are given in Table 2.

Table 1. List of criterion functions and sub-criteria adopted for the research

Criterion functions (f_i)	Sub-criteria (k_{ij})
f_1: The costs of renewal of the cadastral maps (EUR)	k_{11}: The total costs of hiring workers of the geodetic organization
	k_{12}: The costs of public display of survey data
	k_{13}: The material costs
f_2: The time required for the renewal of the cadastral maps (day)	k_{21}: The creation of geodetic-technical and project documentation
	k_{22}: The realization of the project solution
	k_{23}: The public display of survey data and the acceptance of the new database of digital cadastral maps
f_3: The area of the cadastral municipality (ha)	
f_4: The number of real estate deeds (number)	
f_5: The average number of changes to real estate during the year (number)	
f_6: The coverage of the area of the cadastral municipality by the geodetic network (%)	
f_7: The assessment of the degree of outdated data presented on the cadastral maps in relation to the current situation on the ground (%)	
f_8: The possibility of using the existing analogue cadastral maps of graphical survey (grade)	

Table 2. The results of the evaluation of cadastral municipalities as alternative solutions, performed according to each criterion function (f_i)

Criterion function	Measure	Extreme	Alternative				
			Pancevo	Starcevo	Omoljica	Kacarevo	Dolovo
f_1	EUR	min	131 517	49 872.5	48 976	30 130	72 677
f_2	day	min	1225	470	390	238	567
f_3	ha	max	10 429	7 595	7 590	3 980	11 659
f_4	num	max	12 924	4 795	4 252	2 864	5 380
f_5	num	max	420	52	103	74	223
f_6	%	min	100	100	100	70	30
f_7	%	max	10	5	40	20	30
f_8	grade	max	5	5	1	3	1

4.2. Mathematical foundations of the VIKOR method

In this paper, the VIKOR (the acronym in Serbian: VIšekriterijumska optimizacija i KOmpromisno Rešenje, meaning in English: multicriteria optimization and compromise solution) [24] method was applied. This method has been developed to provide compromise solutions to discrete MADM (the acronym: Multiple Attribute Decision-making) problems that include non-commensurable and conflicting criteria [24], which requires that the values of all criterion functions for all alternatives are known, and can be presented in the form of a matrix (Equation 6) [25].

$$\left| f_{ij} \right|_{n \times J} \tag{6}$$

Where i is ordinal number of criterion (i =1, ..., n) and j is ordinal number of variant (alternative) (j=1, ..., J).

Multi-criterion compromise ranking using the VIKOR method is performed by solving following algorithmic steps:

1. Determining the ideal point from the values of the criterion functions using the Equation 7 [26].

$$f_i^* = ext_{ij} f_{ij}, \quad i = 1, \ldots, n \tag{7}$$

Where ext denotes the maximum if the i-th criterion function represents a benefit or profit, or a minimum for damages or costs. The ideal point can also be set by the decision maker by setting the "ideal" values of the criterion functions as "satisfaction levels".

2. Transformation of diverse criterion functions, to apply the compromise ranking metric. In the multi-criteria optimization process, the values of the criterion functions are not expressed in the same units of measurement, that is, the criterion functions are diverse. The Equation 8 is used to transform criterion functions into ones without dimension, with range in interval (0,1) [25].

$$d_{ij} = T\left(f_i^* - f_{ij}\right) = \left[f_i^* - f_{ij}\right] / D_i, \quad i = 1,\ldots,n, \quad j = 1,\ldots,J \tag{8}$$

Where D_i is the length of the range (the length of the value interval) of the i-th criterion function and is represented by the equation $D_i = f_i^* - f_i^-$. For each i-th criterion, f_i^* corresponds to the best alternative of the system (or decision), and f_i^- to the worst.

3. Assigning weight ω_i - criteria weights represent the decision maker's preference. Methods for multi-criteria optimization use normalized weights, where their sum is equal to one.

4. Assigning weight v - the value of v depends primarily on the procedure for making the final decision. Usually, the value of v is 0.5 [27].

5. The following are determined: S_j - measure of satisfaction of most criteria, R_j - measure of minimum individual deviation and Q_j - measure for compromise ranking, where j = 1, ... , J. The value of Q_j is determined as shown in Equation 9 [25].

$$Q_j = vQS_j + (1-v)QR_j, \quad j = 1,\ldots,J \tag{9}$$

The values of QR_j, QS_j, S_j and R_j are obtained using Equations 10 to 13 [26].

$$QR_j = \left(R_j - R^*\right) / \left(R^- - R^*\right) \tag{10}$$

$$QS_j = \left(S_j - S^*\right) / \left(S^- - S^*\right) \tag{11}$$

$$S_j = \sum_{i=1}^{n} \omega_i d_{ij}, \quad i = 1,\ldots,n, \quad j = 1,\ldots,J \tag{12}$$

$$R_j = \max_i \left[\omega_i d_{ij}\right], \quad i = 1,\ldots,n, \quad j = 1,\ldots,J \tag{13}$$

Where S^*, S^-, R^* and R^- are represented by the values $S^* = \max_j S_j$, $S^- = \min_j S_j$, $R^* = \max_j R_j$ and $R^- = \min_j R_j$, respectively.

6. Ranking is achieved through the process of arranging the alternatives based on the measurements of QS, QR, and Q. The optimal alternative is determined by the smallest value of the measure and it is positioned at the top of the ranking list.

7. Compromise solution - The VIKOR method proposes as a multi-criteria best alternative (for given weights ω_i) the one that is in the first position on the compromise ranking list for v = 0.5 only if it has:

- "sufficient advantage" over the alternative from the next position (condition U1)
- "sufficiently firm" first position with change of weight v (condition U2) [26].

Condition U1: The difference between the measures Qj for v = 0.5 is used to evaluate the "advantage". The alternative a' has sufficient advantage over the next a" from the ranking list if $Q(a'') - Q(a') > DQ$ $Q\left(a^{(M)}\right) - Q(a') < DQ$ [28]. DQ is the "advantage threshold" and is determined as shown in Equation 14 [29].

$$DQ = \min\left(0.25; 1/(J-1)\right) \tag{14}$$

Where J is the total number of analyzed alternatives.

Condition U2: The first alternative on the compromise ranking list has a "strong enough" position if it meets at least one of the following conditions:

- has the first position in the ranking list according to Q value for v = 0.25 and v = 0.75,
- has the first position in the ranking list according to QS value,
- has the first position in the ranking list according to QR value.

If the first alternative from the compromise ranking list does not meet both conditions U1 and U2, it is considered that it is not "sufficiently" better than the alternative from the second position. In such cases, the VIKOR method creates a set of compromise solutions that include the first and the alternatives behind it. If the first alternative does not meet only condition U2, then only

the second one from the compromise list is included in the set of compromise solutions. However, if it does not meet condition U1, then the set of compromise solutions contains alternatives from the compromise ranking list a' and a", ..., a(M) for which is $Q\left(a^{(M)}\right)-Q(a')<DQ$ [28].

8. Determining the stability interval - Analyzing the weights and preferential stability of a compromise solution with a change in weights facilitates multi-criteria decision-making, because it avoids the requirement that the decision-maker precisely set the weights of the criteria. Compromise ranking is performed with given (or assumed) initial values of criteria weights [28]. The procedure for analyzing the stability of the solution in relation to weight changes determines "stability intervals" in which the weight values do not affect the initial compromise solution.

5. Results

The multi-criteria ranking list of cadastral municipalities as alternative solutions, and the proposal of a compromise solution, were determined by applying the VIKOR method for four different combinations of weights ω_i, by which different relative importance of criterion functions is expressed.

In the *first combination* (C1) all weights have the same value, i.e. equal importance is given to all criterion functions. In the *second combination* (C2), greater importance is given to the criterion functions f_1 and f_2, which express the economic effects of the cadastral maps' renewal. In the *third combination* (C3), greater importance is given to the criterion functions f_3, f_4 and f_5, which favor the renewal of cadastral maps in cadastral municipalities with a larger area, a greater number of real estate deeds and changes to real estate, while in the *fourth combination* (C4) more importance is given to criterion functions f_6, f_7 and f_8, which favor the renewal of cadastral maps in cadastral municipalities with less developed geodetic network, greater degree of outdated data and worse state of analogue cadastral maps. The adopted weight values are shown in Table 3.

Ranking lists are formed according to measures QR, Q and QS, where QR represents Min/Max strategy, Q represents compromise ranking list and QS represents strategy of most criteria. Ranking lists obtained for every combination of weight values are shown in Table 4.

Table 3. Adopted weights of criterion functions for every combination

Criterion functions	Combinations			
	C1	C2	C3	C4
f_1	0.125	0.2	0.091	0.091
f_2	0.125	0.2	0.091	0.091
f_3	0.125	0.1	0.182	0.091
f_4	0.125	0.1	0.182	0.091
f_5	0.125	0.1	0.182	0.091
f_6	0.125	0.1	0.091	0.182
f_7	0.125	0.1	0.091	0.182
f_8	0.125	0.1	0.091	0.182

Table 4. Ranking lists according to measures QR, Q and QS

Combinations	Alternatives	QR	Q	QS
C1	A5	0.000	0.000	0.000
	A3	0.927	0.648	0.369
	A4	0.960	0.808	0.656
	A1	0.975	0.879	0.782
	A2	1.000	1.000	1.000
C2	A5	0.000	0.000	0.000
	A3	0.138	0.178	0.217
	A4	0.138	0.260	0.382
	A2	0.138	0.465	0.792
	A1	1.000	1.000	1.000
C3	A1	0.000	0.174	0.349
	A5	0.471	0.236	0.000
	A3	0.682	0.590	0.498
	A4	0.995	0.933	0.871
	A2	1.000	1.000	1.000
C4	A5	0.000	0.000	0.000
	A4	0.298	0.443	0.587
	A3	0.968	0.645	0.322
	A1	0.993	0.924	0.855
	A2	1.000	1.000	1.000

6. Discussion

Analyzing the results obtained by the VIKOR method, shown in Table 4, the following conclusions are reached:

1. The proposal for a compromise solution, based on the first combination of weight values of the criterion functions, is alternative A5, i.e., the cadastral municipality of Dolovo. This alternative occupies the first position on the compromise ranking list with the advantage of 64.8% compared to the second-placed one, by which condition of sufficient advantage is satisfied. This alternative also occupies the first position in QR and QS ranking lists, by which the condition of a sufficiently firm first position is fulfilled.

2. The proposal for a compromise solution, based on the second combination of weight values of the criterion functions, is a set of two alternatives A5 and A3, that is, the cadastral municipalities of Dolovo and Omoljica. The cadastral municipality of Dolovo occupies the first position on the compromise ranking list with an advantage of 17.8% compared to the second-placed cadastral municipality of Omoljica, by which condition of sufficient advantage is not satisfied. Even the cadastral municipality of Omoljica, with an advantage of 8.2%, does not satisfy the condition of sufficient advantage compared to the third alternative on the ranking list. The cadastral municipality of Dolovo occupies the first position on the QR and QS ranking lists, by which, in the case of its selection from a set of compromise solutions, the condition of a sufficiently firm first position is fulfilled.

3. The proposal for a compromise solution, based on the third combination of weight values of the criterion functions, is a set of two alternatives A1 and A5, that is,

the cadastral municipalities of Pancevo and Dolovo. The cadastral municipality of Pancevo occupies the first position on the compromise ranking list with an advantage of 6.1% compared to the second-ranked cadastral municipality of Dolovo, by which condition of sufficient advantage is not satisfied. The cadastral municipality of Dolovo, with an advantage of 35.5%, meets the condition of sufficient advantage compared to the third alternative on the ranking list. The cadastral municipality of Pancevo occupies the first position on the QR ranking list, while the cadastral municipality of Dolovo occupies the first position on the QS ranking list, by which, in the case of choosing any of these alternatives from a set of compromise solutions, the condition of a sufficiently firm first position is fulfilled.

4. The proposal for a compromise solution, based on the fourth combination of weight values of the criterion functions, is alternative A5, i.e., the cadastral municipality of Dolovo. This alternative occupies the first position on the compromise ranking list with an advantage of 44.3% compared to the second-placed alternative, by which condition of sufficient advantage is satisfied. This alternative also occupies the first position in QR and QS ranking list, by which the condition of a sufficiently firm first position is fulfilled.

A ranking of alternatives based on the results obtained by the VIKOR method, for four combinations of weights is shown in Figure 3.

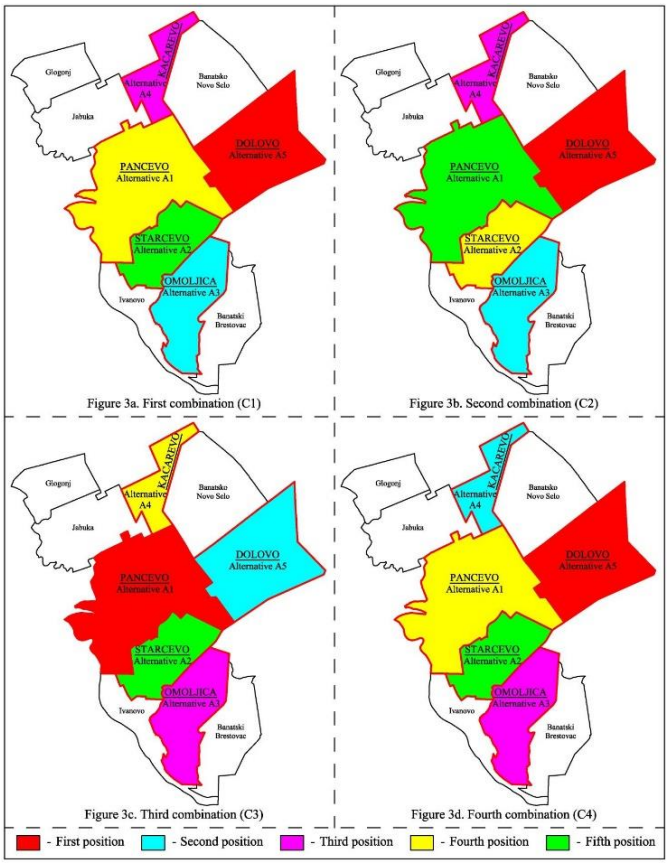

Figure 3. The ranking of alternatives based on the results obtained by the VIKOR method, for four combinations of weights

7. Conclusion

The objective of this research was to conduct a multi-criteria ranking of cadastral municipalities in Serbia using the multi-criteria optimization procedure and the VIKOR method. This analysis aimed to aid in the planning of cadastral map renewal and the decision-making process regarding the commencement of works in one of the cadastral municipalities.

The final solution proposal was decided by evaluating numerical results from the VIKOR method in the multi-criteria ranking of cadastral municipalities. Conclusions were also drawn from four methods of assigning weights to criterion functions.

In the first combination of weight values, the cadastral municipality of Dolovo emerged as the proposed final solution. It exhibited a significant advantage over the second alternative in the ranking list and secured a strong first position. In the second combination of weight values, the proposal for the final solution remained the cadastral municipality of Dolovo. Although it did not possess a substantial advantage over the second alternative in the set of compromise solutions, it did exhibit this advantage when compared to the third-ranked alternative. Thus, the condition of a solid first position for Dolovo was satisfied. The third combination of weight values presented an equal possibility for the final solution to be either the cadastral municipalities of Pancevo or Dolovo. Both alternatives were closely ranked in the set of compromise solutions and demonstrated a sufficient advantage when compared to the third alternative on the ranking list. Additionally, selecting either of these alternatives would fulfill the requirement of a solid first position. Lastly, in the fourth combination of weight values, the proposal for the final solution once again favored the cadastral municipality of Dolovo. It displayed a satisfactory advantage over the second alternative in the ranking list and maintained a sufficiently strong first position.

Based on the comprehensive analysis conducted, the cadastral municipality of Dolovo is proposed as the recommended solution for the decision maker. Upon applying the procedure to adjust the weights of the criterion functions, it was observed that this alternative exhibited a certain level of instability in the third combination of weights. This instability arises when priority is given to the renewal of cadastral maps in cadastral municipalities with larger areas, a greater number of real estate deeds, and significant changes to real estate. Compared to weight combinations that prioritise lower costs and reduced renewal time, as well as a less developed geodetic network, a higher degree of outdated data, and a poorer condition of analogue cadastral maps, this third combination of weights is not of greater significance.

Author contributions

Savanović Rajko: Conceptualization, Methodology, Data processing **Savanović Marija:** Visualization, Investigation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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