Večkriterijska analiza toponimov Republike Srbije

Multicriteria analysis of Toponyms of the Republic of Serbia

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IZVLEČEK

Toponimi imajo velik družbeni, ekonomski, zgodovinski in kulturni pomen za vsako državo, saj so bistven del narodove identitete. Zagotavljajo podlago za identifikacijo in analizo geografskih entitet, ki so prikazane na zemljevidih. V raziskavi je predstavljena večkriterijska analiza toponimov, katere cilj je rangirati toponime, ki bodo prikazani na topografskih zemljevidih različnih meril. Raziskava je bila izvedena v dveh fazah. V prvi so bili določeni ključni kriteriji in ustrezne metode analize. V drugi fazi sta bila izvedena rangiranje toponimov ter evalvacija pridobljenih rezultatov. Da bi dosegli bolj objektivno in realno rangiranje toponimov, sta bili uporabljeni dve analitični metodi. Najprej so bili z metodo OPA določeni utežni koeficienti kriterijev za vsako vrsto toponima, nato pa je bil vsak toponim posebej rangiran z metodo RAFSI. Raziskava je bila izvedena na podatkih, ki so del GIS-a za izdelavo topografskih zemljevidov Republike Srbije.

ABSTRACT

Toponyms have great social, economic, historical, and cultural significance for every country, as they represent a vital part of the nation's identity. They provide a basis for the identification and analysis of geographical entities represented on maps. This paper presents research based on a multicriteria analysis of toponyms, aimed at ranking those toponyms that will be displayed on topographic maps of various scales. The research was conducted in two phases. In the first phase, the key criteria and relevant methods for analysis were defined. In the second phase, the toponyms were ranked, and the obtained results were evaluated. To achieve a more objective and realistic ranking of toponyms, two analytical methods were used. First, the OPA method was applied to determine the weight coefficients for each type of toponym. Then, the RAFSI method was used to rank each toponym individually. The research was conducted using data from the GIS system utilized for the creation of topographic maps of the Republic of Serbia.

KLJUČNE BESEDE

toponim, zemljepisno ime, topografski zemljevid, GIS, kartografija, zbirka podatkov

KEY WORDS

toponym, geographical name, topographic map, GIS, cartography, database

1 INTRODUCTION

Toponyms represent proper names of natural and anthropogenic features on the Earth's surface, serving as unique identifiers of geographic entities on maps. As such, toponyms play an important supplementary role in cartography by enabling map users to better recognize and understand the space, including its physical, historical, and cultural characteristics. The way in which toponyms are selected and displayed on a map significantly influences the readability and functional value of the cartographic representation. This study focuses on the analysis of toponyms shown on topographic maps (TMs), which are among the most important reference sources of geographical names. Toponyms are analyzed in an inseparable relation to the characteristics of the geographical features they designate.Toponyms were stored as annotation feature classes in the spatial geodatabase. An annotation feature class can be a stand-alone feature class or part of a feature dataset, and like other feature classes, each feature has a geographic location and properties. The font, size, color, and other text symbol attributes are all part of each feature's symbology. We employed feature-linked annotation, which is connected to a particular feature in a different geodatabase feature class. A feature-linked annotation's text indicates the value of one or more fields from the feature to which it is related. Features and annotations are connected by a composite relationship with messaging. The annotation feature class is the destination class, and the feature class being annotated is the relationship's origin class. Similar to other composite connections, the destination feature is under the control of the origin feature. The associated annotation based on the attribute immediately updates to reflect any changes made to the attribute value for the origin feature. If you move or rotate the origin feature, the connected annotation will follow suit. When a geodatabase origin feature is removed, the associated annotation feature is likewise removed.

In the process of creating the content of topographic maps, the issue of toponym selection in relation to the scale series arises. Not all toponyms are equally significant for all map scales. For instance, a map at a scale of 1:25,000 requires a detailed representation of local toponyms, while a map at a scale of 1:25,0000 includes only the largest and most important toponyms. During the cartographic generalization of topographic map content, some toponyms are lost due to the reduction or elimination of the features they name. Nevertheless, regardless of this process, it is necessary to select the remaining toponyms according to their relevance for the specific scale of the topographic map.Therefore, it is necessary to conduct a detailed analysis and ranking of toponyms to ensure their relevant representation, taking into account various criteria that align with the procedures of content generalization in topographic maps. Proper ranking contributes to a better spatial representation on topographic maps, ensuring the clarity of cartographic depictions (Peterca et al., 1974). The aim of this study is to improve the process of toponym selection for various scales based on objective criteria, enabling a more detailed and accurate representation of space, while respecting the specific characteristics of the given area.

An excessive effort to include as many toponyms as possible on a map can lead to overcrowding, reducing the visibility of other content and making the map unclear. On the other hand, if too few toponyms are displayed, the map loses its informational value (Borisov, 2017).

In this study, toponyms were analyzed in the context of their functional use on topographic maps. Since each toponym designates a specific geographic feature, the criteria for their selection and ranking are inseparably linked to the physical-geographical, administrative, and cultural-historical characteristics of those features. To ensure a more systematic approach to the analysis, toponyms were classified into four basic groups: oikonyms (names of settlements), hydronyms (names of water features), oronyms (names of relief forms), and choronyms (names of regions) (Stojanović et al., 2024).

From a semantic and philosophical perspective, the relationship between a toponym and the geographical feature it names can be explained through the theory of signs by Morris (1938) and Carnap (1942). According to this theory, the toponym is regarded as a designator, while the geographical feature is the designatum. This theoretical framework clearly separates the linguistic label from the actual entity it refers to, thereby establishing a fundamental distinction between the name and the object it names. As Ormeling (2003) points out, geographical names are designators that identify geographical features both in terms of location and attributes. It is in the interest of cartographers to represent these names correctly on maps, as they play a crucial role in orientation and in indicating the spatial relationships between real-world features, which are defined by geographic coordinates. Therefore, in addition to placing cartographic symbols at the correct feature locations based on their coordinates, which is a basic requirement for maintaining the adequacy of the map as a semiotic model of the real world, toponyms also contribute to the understanding of the map's language, its informational content, and spatial structure (Komedchikov, 2006). Thus, a geographical name has a primary function of naming a place, but it also fulfills both semantic and locational functions (Mollo, 2022).

In modern cartography, toponyms are no longer merely graphical elements on a map, but are also entities within databases, linked to a set of attributes describing the characteristics of the named geographical features. According to the INSPIRE directive, geographical names are part of geographic reference data, meaning that each toponym is associated with a "Named Place" object, which represents a named spatial feature that may include various attributes such as area, population, administrative status, and others (INSPIRE Thematic Working Group Geographical Names, 2024). The geographical name, as a label, reflects these attributes, which directly influence the size, style, and presence of the toponym on the map, depending on the map scale and display context. As a result, the relationship between the toponym (designator) and the feature (designatum) becomes structured, formalized, and directly applicable in processes of digital cartographic generalization and multicriteria analysis.

Although this study analyzes toponyms, the criteria for their ranking inevitably include the characteristics of the features they name, since the meaning and functional value of a toponym on a map depend on those characteristics. This approach is based on contemporary cartographic and semantic interpretations of geographical names, which emphasize that toponyms do not merely indicate location, but simultaneously convey information about the attributes, role, and significance of the features they designate.

The analysis was conducted on a test area located in the lowland region of the Republic of Serbia, rich in hydrographic resources. The test area was analyzed across the entire range of topographic map scales: 1:25,000 (TM25), 1:50,000 (TM50), 1:100,000 (TM100) and 1:250,000 (TM250). This study employs two multicriteria analysis methods, Objective Priority Analysis (OPA) and Ranking of Alternatives through Functional Mapping of Criterion Sub-Intervals into a Single Interval (RAFSI), to determine which toponyms should be highlighted on maps of different scales, taking into account the size of the featurethey name, the density of distribution, and other characteristics that influence the selection of this element.

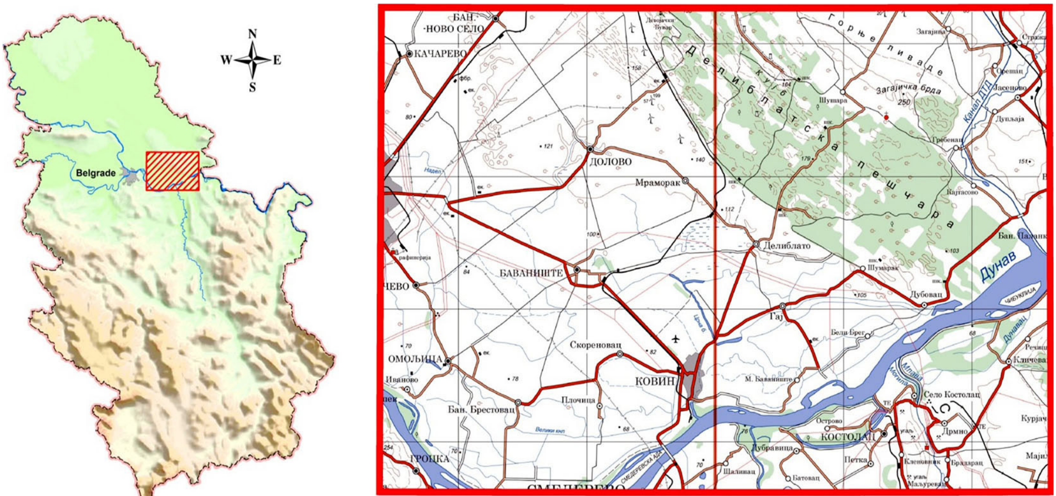
2 MATERIALS AND METHODS

The foundation for creating and publishing topographic maps lies in digital geospatial data organized within databases. The most detailed database is designed for TM25. By modifying this original database, through cartographic generalization processes, the other databases for the series of topographic map scales are derived. The research utilized geospatial data from the Military Geographical Institute in Belgrade (MGI), which is responsible for the production of topographic maps in the Republic of Serbia. Experts in GIS and cartography employed at MGI conducted an objective evaluation of the criteria used in the toponym analysis in this study.

In older editions of MGI topographic maps, the Latin script was used for toponym labeling. In more recent editions of topographic maps, the Cyrillic script is applied, although the database simultaneously contains both Latin and Cyrillic names. This organization allows users to access information in both scripts, facilitating data search and usage. However, since the TM100 map has not yet been derived from the database, the older version of the map, where toponyms are displayed in the Latin script, was used in the provided images.

The research covered a test area where toponyms were ranked based on the features they refer to: oikonyms, hydronyms, oronyms, and choronyms. The test area encompasses part of the TM250 map sheet (NL34-11 Beograd), covers a surface of 1951 km², and includes a total of 887 toponyms (91 oikonyms, 85 hydronyms, 111 oronyms, and 600 choronyms). It is bounded by meridians and parallels, defined by the following geographical coordinates: to the north φ = 45°00' N, to the south φ = 44°40' N, to the east λ = 21°20' E, and to the west λ = 20°40' E. This area overlaps with: one TM100 map sheet (NL34-11/2 Kovin), four TM50 map sheets, and sixteen TM25 map sheets. The majority of the test area belongs to the Autonomous Province of Vojvodina, specifically the South Banat Administrative District. Smaller portions of the area belong to the Branicevo, Podunavlje, and City of Belgrade administrative districts. The terrain of this area is predominantly flat with slight elevations and depressions. It is rich in water resources, intersected by numerous rivers and canals. In addition to the Danube River, with its branches, islands, and the Danube-Tisa-Danube canal system, smaller watercourses are also present. The area includes numerous urban and rural settlements, interconnected by a road network. The landscape is abundant in vegetation, primarily agricultural land and forests, especially in the region of the Deliblatska Sands. Given the large number of toponyms present in the tested area, the detailed analysis results are presented in the supplementary materials (Tables: S1, S2, S3, and S4) to ensure clarity and comprehensiveness of the displayed data. Within the main study, one representative example was selected for each type of toponym, analyzed, and displayed across all topographic map scales, providing insight into how they are presented at different levels of cartographic generalization.

Multicriteria Decision Analysis (MCDA) is becoming increasingly important in the context of geographic information, particularly in GIS and cartography. Various methodologies, such as Analytic Hierarchy Process (AHP), Objective Priority Analysis (OMP), Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Ranking of Alternatives through Functional Mapping of Criterion Sub-Intervals into a Single Interval (RAFSI), Simple Additive Weighting (SAW), and others, are used to rank geographical features for more efficient map representation. Previous studies have shown that the application of multicriteria methods contributes to more precise and objective classification of geographical entities, enabling cartographers to display the most relevant information for users depending on the type and purpose of the map (Basílio et al., 2022). In the analysis of geographical names in cartography, these methods enable the optimal selection of toponyms based on a set of criteria. Selecting appropriate criteria for the analysis is one of the most critical phases of the research, as it directly impacts the quality and relevance of the ranking results. Properly defined criteria allow for an objective evaluation and comparison of the analyzed toponyms, ensuring that all significant aspects, such as the geographical, cultural, historical, and administrative characteristics of the features they refer to, are taken into account.An inadequate or imprecise selection of criteria can lead to erroneous conclusions and compromise the validity of the ranking, thereby reducing the practical value of the analysis (Gigović, Drobnjak and Lukić, 2019).



(a) (b)

Figure 1: (a) Location of test areas in the Republic of Serbia; (b) Details of the test areas on TM250 (VGI, 2021).

To achieve a more objective and realistic ranking of toponyms, two analytical methods were used. First, the OPA method was applied to determine the weight coefficients for the criteria of each type of toponym. Then, the RAFSI method was used to rank each toponym individually. The main idea was to transform the values of different criteria often expressed in varying ranges and units into a uniform scale, enabling easy comparison.

The OPA method is a modern technique for determining criterion weights that is increasingly used in multicriteria analyses. This method was chosen due to its objectivity, simplicity of application, and proportionality in determining weights. Unlike the more complex comparison matrices characteristic of the AHP method, the OPA method uses directly expressed relationships between criteria. It relies on precise numerical values and easily measures the contribution of each criterion. The OPA method is particularly suitable for toponym analysis because it uses several expert assessments for each criterion to determine the weight coefficients. The method works by first normalizing all assigned criterion values to obtain proportional weight shares. Normalization is performed using the following formula (Mahmoudi et al., 2023; Ataei et al., 2020):

$$N_i = \frac{v_i}{\sum_{i=1}^{n} v_i} \quad (1)$$

Where:

N_i – the normalized weight of criterion *i*;

v_i – the value of the criterion (expert evaluation);

n – the total number of criteria.

The weight of each criterion (w_i) is directly expressed as the normalized value:

$$w_i = N_i \quad (2)$$

Since all weights are normalized, their sum always equals 1:

$$\sum_{i=1}^{n} w_i = 1 \quad (3)$$

RAFSI is a multicriteria analysis method that enables the ranking of alternatives by mapping sub-criteria values into a unified interval. The task involves ranking alternatives ($A_1, A_2, \ldots, A_m$), while considering *j*criteria ($C_1, C_2, \ldots, C_n$). This method was chosen for the toponym analysis because it provides objective ranking based on multiple criteria, with a simple and fast process easily adaptable to the specifics of different geographical areas. The method is intuitive and applicable, especially when dealing with a large number of alternatives. The mathematical framework of the RAFSI model does not rely on traditional data normalization models but uses a standardization model. This allows the transformation of data from the initial decision matrix into any interval suitable for rational decision-making (Žižović et al., 2020). The initial decision matrix (*N*) is represented in Equation 4, where n_{11-mn} are the evaluations of the *m*-th alternative based on the *n*-th criterion.

$$N = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{matrix} C_1 & C_2 & \cdots & C_n \end{matrix} \\ \begin{bmatrix} n_{11} & n_{12} & \cdots & n_{1n} \\ n_{21} & n_{22} & \cdots & n_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ n_{m1} & n_{m2} & \cdots & n_{mn} \end{bmatrix} \end{array} \quad (4)$$

For each criterion, ideal (a_{Ij}) and anti-ideal (a_{Nj}), values are defined, which set the boundary values of the criterion interval. The endpoints of the sequence n_1 and n_{2k}, determine how many times the ideal value of a criterion is better than the anti-ideal value. Using the function presented in Equation 5, standardization of the criteria is performed, interpreting the values of the initial decision matrix into the interval (Žižović et al., 2020).

$$f_A(C) = \frac{n_{2k} - n_1}{a_{Ij} - a_{Nj}} \cdot C + \frac{a_{Ij} \cdot n_1 - a_{Nj} \cdot n_{2k}}{a_{Ij} - a_{Nj}} \quad (5)$$

By applying these functions, for each criterion, the elements ($s_{11}, \ldots, s_{mn}$) of the standardized decision matrix (*S*) are obtained (Žižović et al., 2020):

$$S = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} s_{11} & s_{12} & \cdots & s_{1n} \\ s_{21} & s_{22} & \cdots & s_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ s_{m1} & s_{m2} & \cdots & s_{mn} \end{bmatrix} \end{array} \tag{6}$$

By multiplying the criterion weight coefficients ($w_1,\ldots,w_n$) obtained through the OPA method with the standardized elements of the decision matrix ($s_{i1},\ldots,s_{in}$), the criterion functions of the alternatives $V(A_i)$ are calculated, and the alternatives are ranked. This is expressed in Equation 7 (Žižović et al., 2020).

$$V(A_i) = w_1 \cdot s_{i1} + w_2 \cdot s_{i2} + \ldots + w_n \cdot s_{in} \tag{7}$$

The final result is the ranking of each toponym from 1 to 4, where the alternative with the highest value receives the highest rank. Specifically, toponyms with the highest rank (4) are displayed on all scales of topographic maps, while toponyms with the lowest rank (1) are displayed only on the largest-scale topographic map (TM25). It is also important to note that the reduction is not uniform across all types of toponyms. When transitioning to smaller scales, the number of choronyms is reduced the most (as they are the most numerous), followed by hydronyms and oronyms, while oikonyms are reduced by the smallest percentage.

Table 1: Ranking of toponyms for display on TMs.

Rank	TM25	TM50	TM100	TM250
1	✓			
2	✓	✓		
3	✓	✓	✓	
4	✓	✓	✓	✓

The key criteria related to the characteristics of geographic features were defined for the analysis, as these influence the reduction of toponyms when transitioning to smaller-scale topographic maps. Although the criteria primarily pertain to the features themselves, their application enables the ranking of the toponyms that name them, in accordance with their importance for cartographic representation. Thirteen experts in cartography and GIS evaluated each criterion, determining its relative impact in the OPA analysis. The criteria were assessed as follows:

5 - very high impact;
4 - high impact;
3 - moderate impact;
2 - low impact;
1 - very low impact;
0 - no impact.

The average scores are provided in the description of each criterion, although individual scores from each expert for each criterion were used in the OPA analysis. The values for each individual toponym within a specific criterion were taken directly from the TM25 database or indirectly obtained through query processing.

2.1 Criteria for Oikonyms

Oikonyms are the names that undergo the least reduction when transitioning to smaller-scale topographic maps. The following criteria were defined for the analysis of populated places, as they are relevant for the proper ranking and representation of oikonyms on topographic maps: settlement size, administrative status, significance, and settlement distribution density. These criteria allow for the ranking of oikonyms based on the administrative, geographical, and cultural-historical characteristics of settlements, thereby enabling an objective representation of geographical names and the settlements themselves across different map scales. The selection of oikonyms essentially represents the cartographic generalization of populated places, as the name and the named settlement form a functional unit.

Size of settlements, expressed by population, is one of the most important criteria. Larger settlements play a more significant functional role, and they are expected to be highlighted on topographic maps of all scales. Given the average expert score of 4.92, this criterion has a very high impact. Topographic maps distinguish 10 categories of settlements based on population size, and the style of oikonyms is determined in accordance with this classification and editorial decision. (Figure 2). Numerical values were assigned to oikonyms according to the settlement size classification, with a value of 1 assigned to the name of the smallest and 10 to the name of the largestsettlement.The population-based oikonym categories are as follows: names of hamlets– 1, names of settlements with less than 1 000 inhabitants– 2, 1 000 to 2 000 – 3, 2 000 to 5 000 – 4, 5 000 to 10 000 – 5, 10 000 to 25 000 – 6, 25 000 to 50 000 – 7, 50 000 to 100 000 – 8, 100 000 to 500 000 – 9, and names of settlements with more than 500 000 inhabitants – 10.

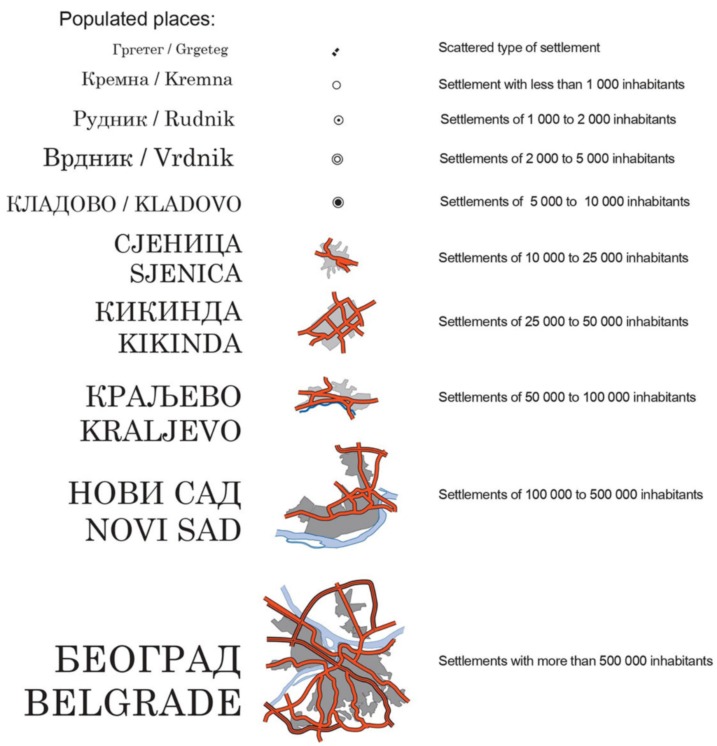


Figure 2: Legend on TM250 for settlements (classification by population)(Marković and Petković Srzentić, 2024).

Administrative status: Oikonyms referring to administrative centers (cities or villages with special status) deserve higher priority for representation on topographic maps. This criterion has a significant impact on the analysis, with the average expert score of 3.85. The administrative status of settlements on topographic maps is classified into four categories, with corresponding impact values for oikonym ranking ranging from 1 to 4, as follows: names of hamlets – 1, names of parts of settlements – 2, names of dispersed-type villages – 3, and names of towns and cities – 4.

Significance of oikonyms is reflected in the geographical location, economic, historical, and cultural significance of a settlement. The names of settlements located in strategic geographical locations can be important for map orientation. Additionally, the names ofsettlements with notable economic roles or rich historical and cultural heritage often deserve emphasis on smaller-scale maps. The average expert score is 2.54, giving this criterion a moderate impact. According to this criterion, oikonyms can have values ranging from 1 to 3, as follows: names of settlements ofminor importance – 1, names of settlements ofmoderate importance – 2, and names of settlements of major importance – 3.

Density of settlement distribution has a significant impact on the reduction of oikonyms, with an average expert score of 3.92. The names of settlements located far from other larger inhabited areas may have greater importance on TMs, as they serve as primary orientation points in less urbanized regions. This criterion helps identify settlements that, although smaller, play a vital role in a broader context due to their isolation. On the other hand, smaller-scale TMs require greater reduction of settlement names in densely populated or clustered areas. Figure 3 displays buffer layers around settlements at three different radii: 500, 1000, and 2500meters, represented in shades of red according to the legend. These buffers illustrate the spatial separation between settlement centers. A visual analysis reveals that some settlements are closely spaced, leading to overlapping buffer zones, while others are more isolated. For this criterion, density categories were defined based on the distance from the center of the nearest settlement, with values ranging from 1 to 4, as follows: less than 500m – 1, 500 to 1000m – 2, 1000 to 2500m – 3, and more than 2500m – 4.

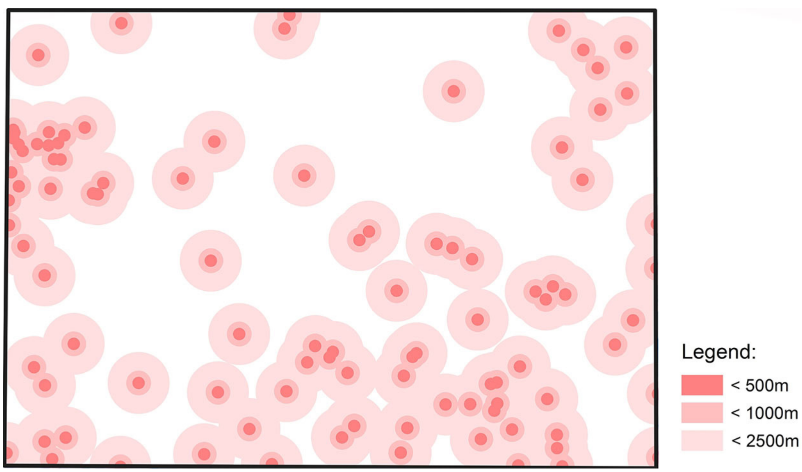


Figure 3: Buffers around settlement centers.

2.2 Criteria for Hydronyms

The following criteria were defined in relation to hydrographic features, but are applied for the analysis of hydronyms: size of the water feature, significance, hydrographic network, and hydrographic type of the feature. These criteria provide a comprehensive analytical framework that takes into account physical characteristics, geographical and economic relevance, as well as cultural and ecological aspects, thereby contributing to a more precise ranking and representation of hydronyms on topographic maps at various scales.Unlike oikonyms, in the case of hydronyms, reduction often does not involve the removal of the feature itself, but only its name.

Size of a water feature, such as the width of a river or the area of a lake, is one of the fundamental criteria. The names of larger water features have a higher chance of being displayed on maps, especially on smaller scales. This criterion ensures that namesof the largest water bodies are visible across all scales and has a very high impact, with an average expert score of 5.00. According to this criterion, hydronyms can have values ranging from 1 to 3, as follows: names of springs and streams narrower than 5m – 1, names of streams 5 to 10m wide – 2, and names of surface water features (scaled streams, lakes, wetlands) – 3.

Significance of hydronyms has an average expert score of 2.89, indicating a moderate impact. This criterion encompasses geographical, economic, ecological, cultural, and historical significanceof the named features. Hydronyms referring to water features with important roles (e.g., regional boundaries, natural barriers, primary water supply sources) have greater importance for cartographic representation. According to this criterion, hydronyms can have values ranging from 1 to 3, as follows: names of water features of minor importance – 1, names of water features of moderate importance – 2, and names of water features of major importance – 3.

Hydrographic network: The names of water features that are part of a broader hydrographic network, such as major tributaries or lake systems, should be prioritized for representation as they contribute to a better understanding of the hydrological system. The names of longer watercourses that are part of significant watersheds or lake systems should be highly ranked. Additionally, in areas rich in water features, the reduction of hydronyms must be more radical. This criterion has a high impact, with an average expert score of 4.15. According to this criterion, hydronyms can have values ranging from 1 to 3, as follows: names of linear branches, oxbows, intermittent streams, and streams shorter than 500m – 1, names of springs, wetlands, surface branches and oxbows, and linear streams 500 to 2500m long – 2, and names of surface water featuresand linear streams longer than 2500m – 3.

Hydrographic type of water features has a significant impact on the ranking of hydronyms, with an average expert score of 3.58. This criterion relates to the type of water features, distinguishing between lakes and wetlands, which may have the same surface area but not the same priority for name representation on smaller scales. According to this criterion, hydronyms can have values ranging from 1 to 3, as follows: names of wetlands – 1, names of all linear features – 2, and names of other surface water features and springs – 3.

2.3 Criteria for Oronyms

The following criteria were defined in relation to landforms and are applied tothe analysis of oronyms: size of the orographic feature, dominance of the landform, significance, and distribution density. These criteria aim to enable a comprehensive analysis of oronyms, taking into account their physical characteristics, as well as their cultural, economic, and ecological importance, which contributes to their proper ranking on topographic maps of different scales.Given the complexity of representing terrain on topographic maps, particularly through symbols such as contour lines which serve a quantitative and morphological function, oronyms are viewed as elements with a specific interpretative framework, as they introduce a qualitative layer of meaning through their location and naming. Therefore, the nature of the landform itself, especially its spatial characteristics, influences the selection and placement of oronyms.The selection of oronyms essentially represents the cartographic generalization of landforms, as geographical names serve as key carriers of meaning in the interpretation of terrain.

Size of the orographic feature, referring to the area or spatial extent of mountain ranges, is important for ranking oronyms. Large mountain ranges or extensive plateaus have greater territorial significance, and their names are therefore essential for representation on topographic maps. Larger relief units play a prominent role on smaller-scale maps, and the criterion is defined based on the size of the orographic feature (mountains, hills, slopes, hillsides, valleys, gorges, etc.). This criterion has a very high impact, with an average expert score of 5.00. According to this criterion, oronyms can have values ranging from 1 to 9, as follows: names of landforms smaller than 500m – 1, 500 to 1000m – 2, 1000 to 2000m – 3, 2000 to 3000m – 4, 3000 to 4000m – 5, 4000 to 5000m – 6, 5000 to 7500m – 7, 7500 to 10000m – 8, and names of landformsgreater than 10000m – 9.

Dominance of a relief feature in the geographical space, whether due to its position or size, must hold special significance. This criterion encompasses oronyms that represent the key landmarks in a region, such as dominant peaks or mountain ranges that define entire geographical areas. The average expert score is 4.62, which gives this criterion a very high impact. According to this criterion, oronyms can have values ranging from 1 to 3, as follows: names of less dominant landforms – 1, names of moderately dominant landforms – 2, and names of dominant landforms – 3.

Significance of oronyms includes geomorphological, cultural-historical, economic, and ecological aspects of a landform. Furthermore, names of landforms that contain important natural resources deserve a higher rank.This criterion has a moderate impact, with an average expert score of 2.65. Based on this criterion, oronyms are assigned values from 1 to 3, categorized as follows: names of landforms of minor importance – 1, names of landforms of moderate importance – 2, and names of landforms of major importance – 3.

Density of landform distribution has an average expert score of 3.75, giving it a significant impact on the ranking of oronyms. Isolated oronyms have a greater chance of being displayed on smaller scales. The reduction of oronyms is greater in areas with higher density of orographic features. Figure 4 displays buffer layers around the centers of landforms, where different radii are marked in shades of red. According to the legend, buffers are defined for the following distances: 500, 1000, and 2500 meters. These layers enable the analysis of the spatial distribution of landforms and their mutual influence, which is useful for cartographic generalization. According to this criterion, oronyms can have values ranging from 1 to 4, as follows: less than 500m – 1, 500 to 1000m – 2, 1000 to 2500m – 3, and more than 2500m – 4.

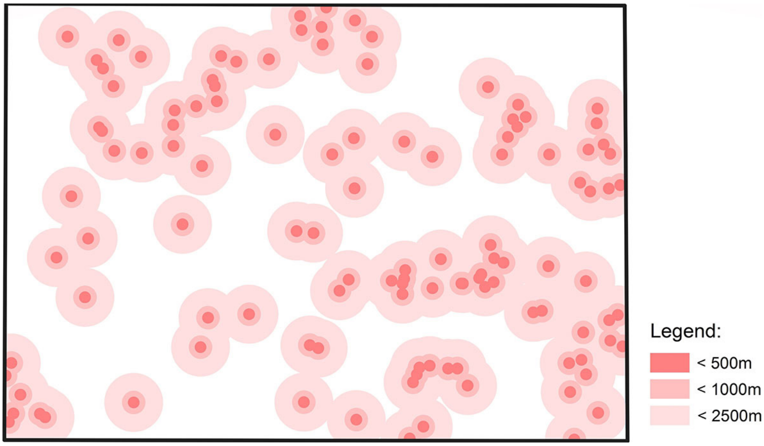


Figure 4: Buffers around relief feature centers.

2.4 Criteria for Choronyms

The following criteria were defined based on the spatial and functional characteristics of regions, but are applied tothe analysis of choronyms: area size, significance, administrative status, and distribution density. These criteria enable a holistic approach to choronym analysis, considering both spatial characteristics and the cultural and administrative aspects of a region, which contributes to better selection and representation on topographic maps of different scales.The selection of names constitutes the cartographic generalization of regions, as choronyms enable the identification and semantic interpretation of broader geographic areas.

Size of the area is a criterion with a very significant impact, with an average expert rating of 4.77. Choronyms designate large administrative or geographical units. The spatial size of the area is a key criterion because the names of larger territories hold greater importance on maps of smaller scales. Based on this criterion, choronyms can have values ranging from 1 to 8, depending on the spatial size of the area they refer to, as follows: names of regions smaller than 1000m – 1, 1000 to 2000m – 2, 2000 to 3000m – 3, 3000 to 4000m – 4, 4000 to 5000m – 5, 5000 to 7500m – 6, 7500 to 10000m – 7, and names of regions larger than 10000m – 8.

Significance of choronyms encompasses geographical features, cultural-historical relevance, and public recognitionof the region. This criterion evaluates the natural or geographical specificities of the region. Choronyms referring to areas with prominent physical-geographical characteristics are significant for topographic maps as they denote natural entities important to map users. Additionally, choronyms recognizable to the general public, whether due to their touristic popularity or historical value, often deserve a higher rank. The average expert rating is 3.23, indicating that this criterion has a moderate influence. Individual choronyms can have values ranging from 1 to 3, as follows: names of regions of minor importance – 1, names of regions of moderate importance – 2, and names of regions of major importance – 3.

Administrative status of an area has a significant impact on the ranking of choronyms, as the average expert rating is 4.15. Choronyms associated with administrative units often hold a higher rank, highlighting the names of countries or provinces over the names of other areas. Based on this criterion, choronyms can have values ranging from 1 to 2, as follows: names of areas – 1, and names of countries and provinces – 2.

Density of distribution has an average expert rating of 4.00, indicating a significant impact on the ranking of choronyms. In areas with a high number of choronyms, distribution density can play a key role in deciding which choronyms will be displayed on maps. On small-scale topographic maps, it is not possible to displaythe names of all units, so choronyms in densely populated areas must be more selectively chosen. This criterion allows for balancing the accuracy of representation with map readability, which is especially important for smaller-scale maps. Figure 5 displays buffer layers around the centers of regions, with zones of different radii marked in shades of red. According to the legend, buffers are defined for the following distances: 500, 1000, and 2500 meters. It can be observed that the regions are densely distributed, leading to significant overlap of buffer zones, especially in the central parts of the test area. This distribution indicates a high spatial density of horonyms, which is important for their analysis and selection. According to this criterion, individual choronyms can have values ranging from 1 to 4, as follows: less than 500m – 1, 500 to 1000m – 2, 1000 to 2500m – 3, and more than 2500m – 4.

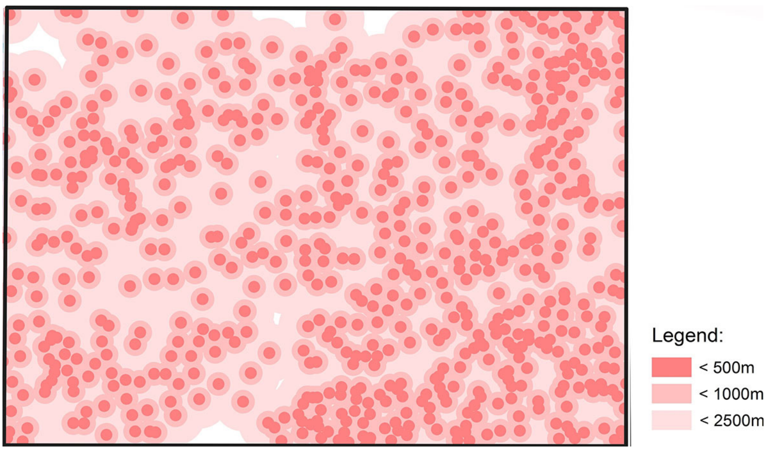


Figure 5: Buffers around the center of area.

3 RESULTS

The OPA Solver Version 1.4 was used to determine the weight coefficients of the criteria. This web-based application, built around tables, can solve multicriteria decision analysis problems. It has no limitations regarding the number of experts, criteria, or alternatives. OPA Solver 1.4 can calculate the reliability levels for the input data of the OPA model. Additionally, it can measure uncertainty in group decision-making using the OPA interval. It is user-friendly and freely available to researchers interested in applying the rank-order approach to multicriteria decision analysis problems (Mahmoudi et al., 2023; Ataei et al., 2020). The criteria for each type of toponym were entered into the Solver, along with individual criterion ratings provided by each of the 13 experts, all of whom were equally ranked. This method was used exclusively to determine the weight coefficients of the criteria, which were subsequently applied in the RAFSI method for ranking alternatives. For the technical implementation of the RAFSI method and data processing, Excel was utilized, enabling efficient application of the method while adapting its algorithm to the specific needs of the toponym analysis.

3.1 Ranking of Oikonyms

Based on the assessment of the impact of each defined criterion for oikonyms, the weight coefficients for each criterion are determined, representing their influence in the final ranking of toponyms. Figure 6 illustrates the reliability levels of expert evaluations oikonym criteria, while Table 2 presents the weight coefficients for oikonym criteria obtained using the OPA method (Mahmoudi et al., 2023; Ataei et al., 2020).

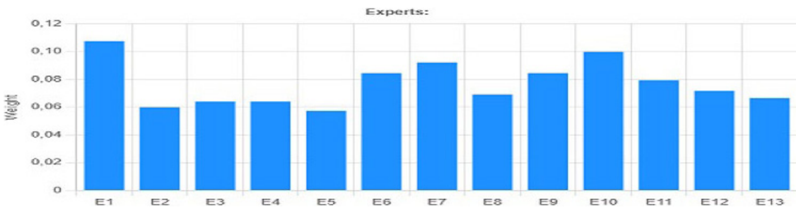


Figure 6: Level of reliability of expert ratings for oikonyms criteria in the OPA method.

Table 2: Criterion weight coefficients for oikonyms obtained using the OPA method.

Criteria	Size	Administrative status	Significance	Density
Weight	0.383828	0.246673	0.127943	0.241556

The obtained weight coefficient values for the criteria, along with the alternative evaluations for each criterion, serve as input parameters for the RAFSI analysis. The diagram in Figure 7 shows the percentage distribution of oikonyms by rank. The largest percentage (37%) consists of oikonyms with a rank of 2, indicating that most settlement names are displayed on TM25 and TM50. They are followed by oikonyms with a rank of 1 (27%), which are the least significant and appear only on the largest-scale maps – TM25. Rank 4, accounting for 24% of oikonyms, represents the most important toponyms that are displayed across all topographic map scales. The lowest percentage belongs to rank 3 (12%), suggesting a relatively lower presence of oikonyms that appear on TM25, TM50, and TM100. These results confirm the varying importance of oikonyms based on the applied criteria, enabling selective representation on topographic maps of different scales.

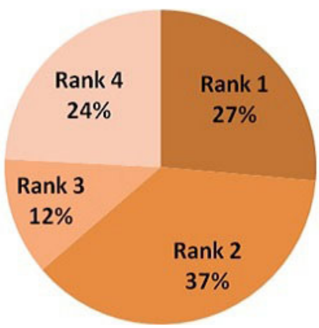


Figure 7: Diagram of the percentage ranking of oikonyms on TM.

In the supplementary materials (Table S1), the ranking of all oikonyms from the test areas is presented, while Table 3 shows a portion of the main table with an example of the ranking for the settlement Gaj. According to the 2022 census, this settlement has a population of 2486, which gives it a score of 4 based on the Size criterion (Ukupan broj stanovnika po naseljima, 2022). Given that Gaj is a small town, it also receives a score of 4 for the Administrative status criterion. Its moderate importance under this criterion results in a score of 2, while its distance from other settlements, exceeding 2500 meters, earns it a score of 4 for the Density criterion. The overall rank of this oikonym is 4, indicating that it should be displayed on topographic maps of all scales.

Table 3: Part of the Table S1 – Ranking of the settlement name Gaj.

No	Feature ID	Name	Size	Administrative status	Significance	Density	Score	Rank
18	73534	Gaj	4	4	2	4	0.5057	**4**

Figure 8 illustrates the settlement Gaj across the full range of topographic map scales. The presence of this oikonym at all levels of detail confirms its high rank, indicating the spatial, administrative, and cultural significanceof this settlement. The obtained results validate that the ranking of oikonyms, conducted using the RAFSI method, is effective and aligns with the actual needs of cartographic representation.

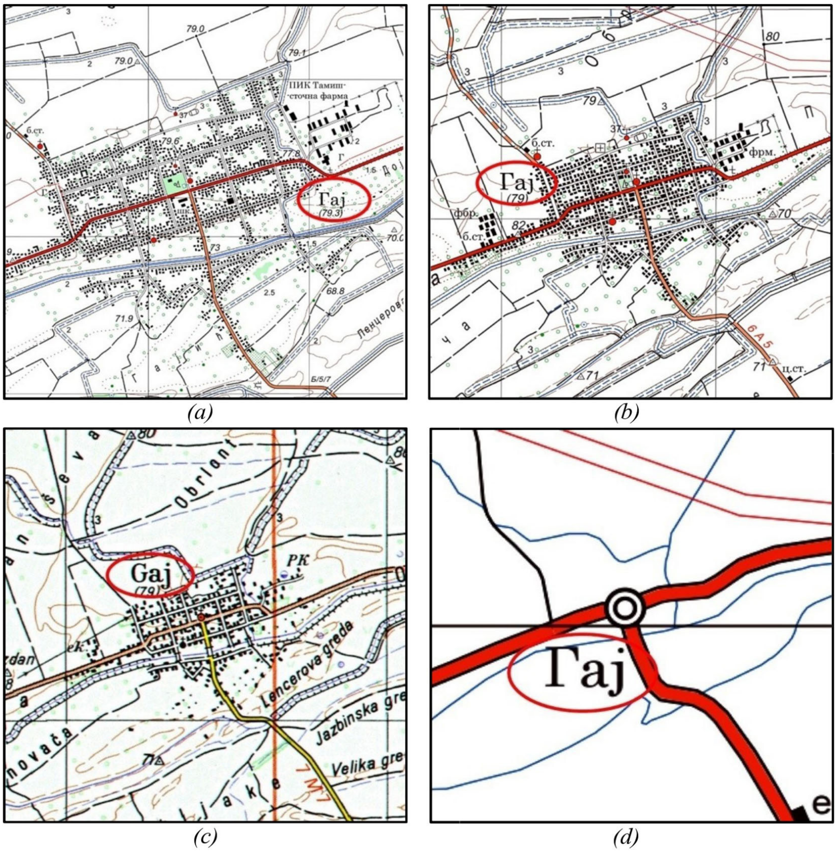


Figure 8: Display of the settlement name Gaj: (a) on TM25 (VGI, 2018), (b) on TM50 (VGI, 2023), (c) on TM100 (VGI, 1986), (d) on TM250 (VGI, 2021).

3.2 Ranking of Hydronyms

Based on the assessment of the impact of each defined criterion for hydronyms, the weight coefficients for each criterion were determined, representing their influence on the final ranking of toponyms. Figure 9 shows the reliability levels of expert evaluations for hydronym criteria, while Table 4 presents the weight coefficients for hydronym criteria obtained using the OPA method (Mahmoudi et al., 2023; Ataei et al., 2020).

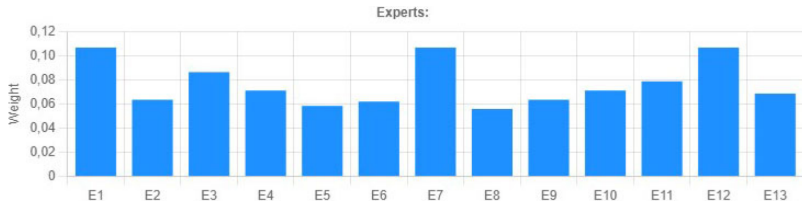


Figure 9: Level of reliability of expert ratings for hydronyms criteria in the OPA method.

Table 4: Criterion weight coefficients for hydronyms obtained using the OPA method.

Criteria	Size	Significance	Hydrographic network	Hydrographic type
Weight	0.396543	0.134723	0.261820	0.206914

The obtained weight coefficient values for the criteria, along with the alternative evaluations for each criterion, serve as input data for the RAFSI analysis. The diagram in Figure 10 illustrates the percentage distribution of hydronyms by rank. The largest percentage (33%) belongs to rank 3, indicating that most hydronyms are displayed on TM25, TM50, and TM100. Rank 1, which includes 26% of the hydronyms, represents the least significant hydronyms that are displayed only on the largest-scale maps –TM25. Hydronyms with rank 2 account for 23%, while rank 4, representing the most significant hydronyms displayed across all scales, is the least represented, with 18%. This distribution highlights a greater concentration of hydronyms in the middle ranks (2 and 3) and their selective importance in the cartographic representation process.

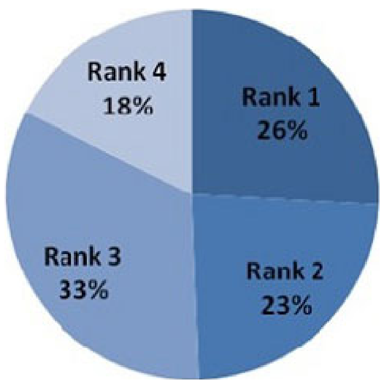


Figure 10: Diagram of the percentage ranking of hydronyms on TM.

In the supplementary materials (Table S2), the ranking of all hydronyms from the test areas is presented, while Table 5 provides a portion of the main table with an example of the ranking for the watercourse Dunavac. This example explains the method of ranking hydronyms based on defined criteria using the RAFSI method. This feature is one of the main branches of the Danube River, and due to its width, it is represented as a polygon element on TM25. For this reason, the hydronym received the highest score of 3 for the Size criterion. Given that it is one of the main branches and has significant geographical, economic, and historical importance, it also received the highest score of 3 for the same criterion. Since it is a river branch displayed at the TM25 scale, it was assigned a score of 2 for the Hydrographic network criterion. For the Hydrographic type criterion, it received a score of 3 because branches at this map scale are represented as polygon elements. Based on the given scores for all criteria, the RAFSI method determined the highest rank of 4 for Dunavac, meaning this hydronym will be displayed on topographic maps of all scales.

Table 5: Part of the Table S2 – Ranking of the stream name Dunavac.

No	Feature ID	Name	Size	Significance	Hydrographic network	Hydrographic type	Score	Rank
31	33231	DUNAVAC	3	3	2	3	0.3767	**4**

Figure 11 shows a section of the Dunavac watercourse across all scales of topographic maps. Thepresence of this name throughout the entire range of scales highlights the high significance of this hydronym, as determined by the applied analysis criteria. The results confirm the validity of the ranking, where hydronyms with the highest rank – 4, are consistently represented across all cartographic levels.

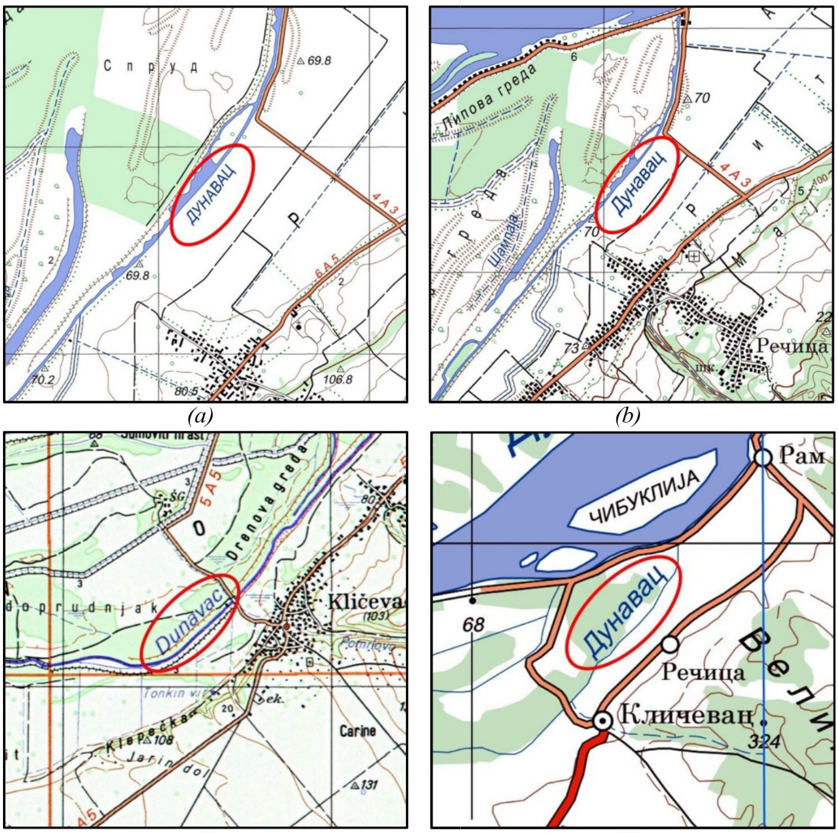


Figure 11: Display of the stream name Dunavac: (a) on TM25 (VGI, 2018), (b) on TM50 (VGI, 2023), (c) on TM100 (VGI, 1986), (d) on TM250 (VGI, 2021).

3.3 Ranking of Oronyms

Based on the assessment of the impact of each defined criterion for oronyms, the weight coefficients for each criterion were determined, representing their influence on the final ranking of toponyms. Figure 12 shows the reliability levels of expert evaluations for oronym criteria, while Table 6 presents the weight coefficients for oronym criteria obtained using the OPA method (Mahmoudi et al., 2023; Ataei et al., 2020).

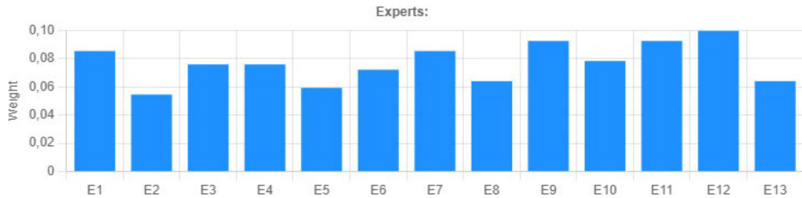


Figure 12: Level of reliability of expert ratings for oronyms criteria in the OPA method.

Table 6: Criterion weight coefficients for oronyms obtained using the OPA method.

Criteria	Size	Dominance	Significance	Density
Weight	0.370195	0.308495	0.121025	0.200285

The obtained weight coefficient values for the criteria, along with the alternative evaluations for each criterion, serve as input data for the RAFSI analysis. The diagram in Figure 13 illustrates the percentage distribution of oronyms by rank. Each rank accounts for an equal share of 25%, indicating a uniform representation of oronyms. Such an even distribution suggests a balance in the ranking of oronyms, indicating a uniform reduction of oronyms when transitioning to smaller-scale TM.

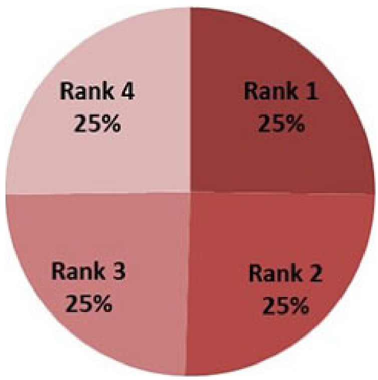


Figure 13: Diagram of the percentage ranking of oronyms on TM.

In the supplementary materials (Table S3), the ranking of all oronyms from the test areas is presented, while Table 7 provides a portion of the main table with an example of the ranking for the landform Zagajicka brda. This landform spans approximately 900 meters, which assigns the oronym a score of 2 for the Size criterion. Given that Zagajickabrda is a dominant elevation on the slopes of the Deliblato Sands, it received the highest scores of 3 for both the Dominance and Significance criteria. Additionally, its distance from other landforms, ranging between 1000 and 2500 meters, gives it a score of 3 for the Density criterion. Based on these scores across all criteria, the RAFSI method assigned it the highest rank of 4, meaning that this oronym should be displayed on topographic maps of all scales.

Table 7: Part of the Table S3 – Ranking of the landform name Zagajicka brda.

No	Feature ID	Name	Size	Dominance	Significance	Density	Score	Rank
50	62708	Zagajicka brda	2	3	3	3	0.3628	**4**

Figure 14 displays the landform Zagajicka brda across all scales of topographic maps. The presence of this oronym throughout the entire range of scales highlights its great importance, as confirmed by the applied analysis criteria. The results indicate the validity of the ranking, where oronyms of the highest category – rank 4, are consistently represented on all scales of topographic maps.

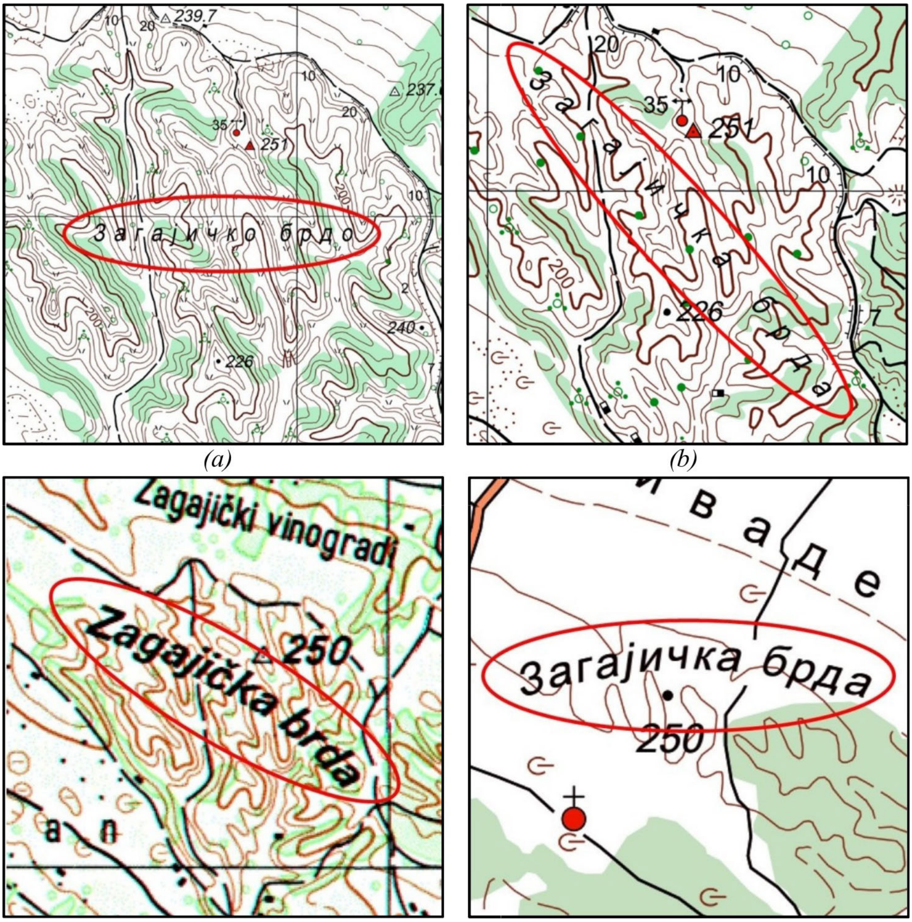


Figure 14: Display of the landform name Zagajicka brda: (a) on TMK25 (VGI, 2016), (b) on TM50 (VGI, 2023), (c) on TM100 (VGI, 1986), (d) na TM250 (VGI, 2021).

3.4 Ranking of Horonyms

Based on the assessment of the impact of each defined criterion for choronyms, the weight coefficients for each criterion were determined, representing their influence on the final ranking. Figure 15 shows the reliability levels of expert evaluations for choronym criteria, while Table 8 presents the weight coefficients for choronym criteria obtained using the OPA method (Mahmoudi et al., 2023; Ataei et al., 2020).

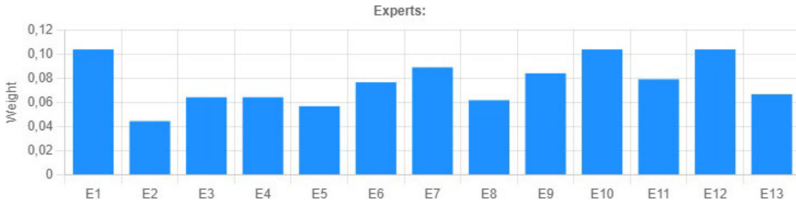


Figure 15: Level of reliability of expert ratings for choronym criteria in the OPA method.

Table 8: Criterion weight coefficients for horonyms obtained using the OPA method.

Criteria	Size	Significance	Administrative status	Density
Weight	0.351485	0.153465	0.267327	0.227723

The obtained weight coefficient values for the criteria, along with the alternative evaluations for each criterion, serve as input data for the RAFSI analysis. The diagram in Figure 16 presents the results of choronym ranking using the RAFSI method, displayed as a pie chart for clear visualization of the proportional representation of individual ranks. The lowest rank – 1, accounts for 36%, indicating that the majority of choronyms are displayed only on TM25. Choronyms with ranks 2 and 3 are moderately represented, while the smallest share, only 15%, is assigned to choronyms with rank 4, indicating those that are displayed across all TM scales. This distribution provides a detailed overview of the importance of choronyms in accordance with the defined criteria of the multicriteria analysis.

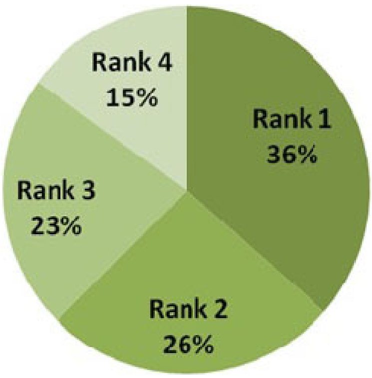


Figure 16: Diagram of the percentage ranking of choronyms on TM.

In the supplementary materials (Table S4), the ranking of all choronyms from the test areas is presented, while Table 9 provides a portion of the main table with an example of the ranking for the area Gornje livade. This area spans approximately 9000 meters, which gives this choronym a score of 7 for the Size criterion. Gornje livade is an area of lesser importance, which results in a score of 1 for both the Significance and Administrative status criteria. Its distance from other areas, ranging between 500 and 1000 meters, gives it a score of 2 for the Density criterion. Based on these scores across all criteria, the RAFSI method assigned it the highest rank of 4, meaning that this choronym will be displayed on topographic maps of all scales.

Table 9: Part of the Table S4 – Ranking of the landscape name Gornje livade.

No	Feature ID	Name	Size	Significance	Administrative status	Density	Score	Rank
139	58121	Gornje livade	7	1	1	2	0.4534	**4**

Figure 17 illustrates the area Gornje livade across all scales of topographic maps. Its presence throughout the entire range of scales highlights the exceptional importance of this choronym, as confirmed by the analysis results based on the defined criteria. The ranking demonstrated consistency, with choronyms of the highest category – rank 4, consistently represented on all scales of topographic maps.

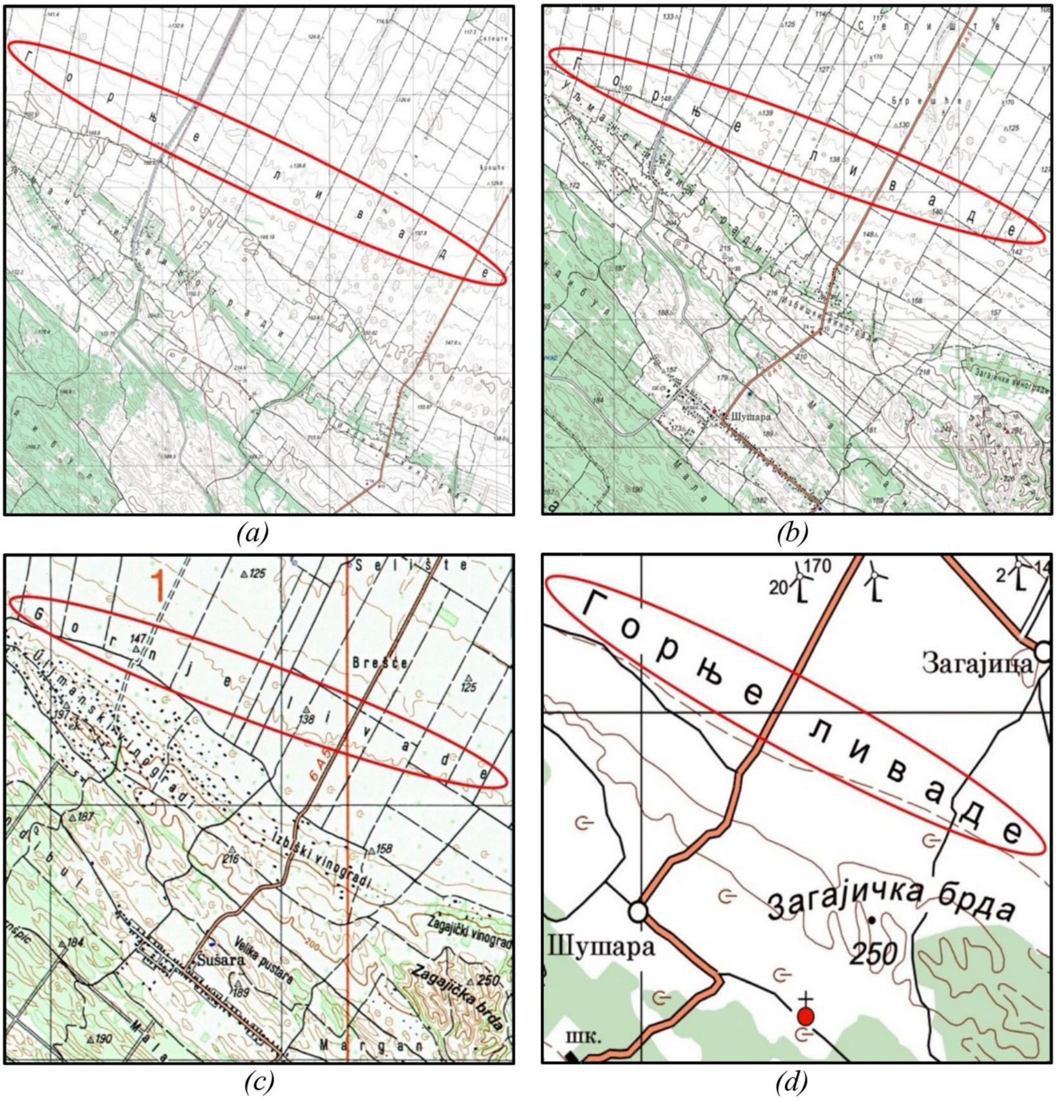


Figure 17: Display of the landscape name Gornje livade: (a) on TM25 (VGI, 2016), (b) on TM50 (VGI, 2023), (c) on TM100 (VGI, 1986), (d) on TM250 (VGI, 2021).

4 DISCUSSION AND CONCLUSIONS

The results of the multicriteria analysis of toponyms, obtained through the application of the OPA and RAFSI methods, provide an objective basis for ranking various types of toponyms, thereby enhancing their representation on topographic maps of all scales. Through the systematic evaluation of relevant criteria and the objective determination of weight coefficients, this approach takes into account various aspects of the geographical, historical, and cultural values of toponyms. This analysis contributes to the standardization and harmonization of the representation of geographic names, reducing subjectivity in their selection for depiction on topographic maps.

The results indicate that certain toponyms, such as oikonyms, are more dominant on smaller-scale maps (TM250), while choronyms appear more frequently on more detailed maps (TM25 and TM50). This distribution confirms the assumption that different types of toponyms serve specific roles in cartographic representation, aligning with previous studies that emphasize the importance of the functional depiction of toponyms depending on the map scale. From a broader perspective, these results may have implications for improving cartographic standards, particularly in terms of scientific or educational objectives. Additionally, objective toponym ranking contributes to their more accurate selection and representation, enhancing the readability and informational value of maps.

For a visual illustration of the ranking of geographical names on TM, only the highest-ranked toponyms for each type were displayed to ensure clarity and readability in the cartographic representation. Displaying all toponyms simultaneously could lead to an unclear depiction on larger-scale TMs and make the interpretation of analysis results more difficult. A selective display allows for a focus on the most important toponyms according to the defined ranking criteria, while all other toponyms are available in the supplementary materials (Tables: S1, S2, S3, and S4)to ensure data completeness and provide a detailed insight into the analysis. This approach ensures that the visualization remains functional and adapted to different topographic map scales.

Although the ranking of toponyms using multicriteria analysis has produced good results, the final visualization requires additional spatial analysis using GIS technology. GIS spatial analysis enables a detailed examination of the spatial relationships between toponyms and other elements of topographic maps. As part of this analysis, the ranked toponyms were compared with the same toponyms from the test areas across the full scale range of topographic maps, revealing a significant correspondence between the results obtained through the multicriteria approach and the existing cartographic solutions. This approach allows for the consideration of spatial distribution and the interrelationships among elements, thereby contributing to a more accurate representation and interpretation of toponyms. The integration of multicriteria results with GIS tools provides a reliable basis for decision-making in the process of cartographic generalization and toponym selection.Future research directions can follow several paths. First, the analysis can be expanded by incorporating additional criteria, derived from a more detailed breakdown of existing ones. For example, the Significance criterion could be subdivided into cultural, historical, economic, ecological, and other aspects, allowing for even more precise ranking of toponyms based on their functional and symbolic importance. Second, the use of alternative methods, such as the previously mentioned AHP, PROMETHEE, TOPSIS, SAW, and others, could contribute to a deeper understanding of toponym ranking and enable a comparative analysis of different multicriteria evaluation approaches. Third, while this research establishes a foundation for toponym ranking, its application to another test area with different geographical characteristics would allow for a comparison of various ranking approaches in different geographical, cultural, and administrative contexts.

The results of this research provide valuable guidelines for the further development of cartographic practices and methodologies in the field of toponym analysis, ensuring their more efficient representation and preservation for future generations.

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Tables S1, S2, S3, and S4 are only avalibale on website of Geodetski vestnik:

https://www.geodetski-vestnik.com/arhiv/69/3/Table-S1_Ranking-of-oikonyms-on-TM.pdf
https://www.geodetski-vestnik.com/arhiv/69/3/Table-S2_Ranking-of-hydronyms-on-TM.pdf
https://www.geodetski-vestnik.com/arhiv/69/3/Table-S3_Ranking-of-oronyms-on-TM.pdf
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