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Clustering of sacred objects of Ivano-Frankivsk Oblast as a modern tool of sacred geography zoning

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Abstract. In this paper, we present a clustering of sacred objects of Ivano-Frankivsk Oblast using mathematical-statistical methods for the purpose of sacred-geography zoning of the area. Great attention was paid to the methodology of cluster analysis and the employment of geoinformation systems (GIS) for modeling the foundational connections among the objects

of sacred geography. We described the stages of clustering and provided a validation for them: collection and preparation of the data, selection of metrics of similarity, identification of optimal number of clusters, cluster analysis, evaluation of the results, and designation of sacred-geography districts. To perform the clustering, we employed the k-means method, which allows the designation of groups of objects in geospace that are compactly located. We developed a validation for choosing the metrics of similarity and criteria of evaluating the results of clustering (inertia of k-means and silhouette score). The utilized similarity metrics take into account geographic distances (Euclidean distance for geographic coordinates). The cluster analysis was conducted based on geographic coordinates of 69 natural-anthropogenic and 614 anthropogenic sacred objects. The analysis of the inertia graphs and silhouette confirmed that the optimal number of clusters is five. Based on the clustering, we carried out sacred-geography zoning of Ivano-Frankivsk Oblast, where each cluster corresponds to a certain district. Boundaries of the clusters correspond to designated districts. For each district, we determined a centroid (point that determines the mean position of objects on the plane defined by geographic coordinates). The established centroids are settlements such as the villages Bratkiivtsi and Vyhivka of Ivano-Frankivsk District, the Verhnii Strutyn village of Kalush District, the Prokurava village of Kosiv District, and the Slobidka village of Kolomyia District. Within the oblast, five sacred-geography districts were designated: Opilskyi, Boikivsko-Hutsulskyi, Opilsko-Pokutskyi, Pokutskyi, and Hutsulsko-Pokutskyi. Such names of the sacred-geography districts are based on the cultural-historical, geographic, and ethnographic peculiarities of each territory. The results of the clustering are valuable for the development of tourist-recreation activity, preservation of historical-cultural heritage, and the development of communities based on the principals and objectives of sustainable development.

Keywords: clustering, sacred object, zoning, Ivano-Frankivsk Oblast, sustainable development

Кластеризація сакральних об'єктів Івано-Франківської області як сучасний інструмент сакральньо-географічного районування

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Анотація. Наведено кластеризацію сакральних об'єктів Івано-Франківської області із застосуванням математично-статистичних методів з метою сакральньо-географічного районування території. Значну увагу приділено методології кластерного аналізу та використанню геоінформаційних систем (ГІС) для моделювання системоутворюючих зв'язків між об'єктами сакральної географії. Описано та обґрунтовано етапи виконання кластеризації: збір та підготовка даних, вибір метрики схожості, визначення оптимальної кількості кластерів, кластерний аналіз, оцінка результатів і виокремлення сакральньо-географічних районів. Для здійснення кластеризації застосовано метод k-means, який дозволяє виокремити групи об'єктів, що компактно розташовані в геопросторі. Обґрунтовано вибір метрик схожості та критеріїв оцінки результатів кластеризації (інерція k-середніх і оцінка силуету). Використана метрика схожості враховує географічні відстані (евклідова відстань для географічних координат). Кластерний аналіз проведено на основі географічних координат 69 природно-антропогенних та 614 антропогенних сакральних

об'єктів. Аналіз графіків інерції та силуету довів, що оптимальною кількістю кластерів є 5. На основі кластеризації було виконано сакральньо-географічне районування території Івано-Франківської області, де кожному кластеру відповідає певний район. Межі кластерів відповідають межах виокремлених районів. Для кожного району визначений центроїд (точка, яка визначає середнє положення об'єктів на площині, задана географічними координатами). Визначеними центроїдами є такі населені пункти: с. Братківці та с. Вигівка Івано-Франківського району, с. Верхній Струтинь Калузького району, с. Прокурава Косівського району, с. Слобідка Коломийського району). В межах області об'єднано п'ять сакральньо-географічних районів: Опільський, Бойківсько-Гуцульський, Опільсько-Покутський, Покутський, Гуцульсько-Покутський. Такі назви сакральньо-географічних районів ґрунтуються на культурно-історичних, географічних та етнографічних особливостях кожної території. Результати кластеризації мають вагоме практичне значення для розвитку туристично-рекреаційної діяльності, збереження історико-культурного надбання, поступу громад на засадах і цілях сталого розвитку.

Ключові слова: кластеризація, сакральний об'єкт, районування, Івано-Франківська область, сталий розвиток.

Introduction

Over recent decades, sacred geography – as a scientific discipline – garners increasing interest in the sphere of nature sciences, culturology, and religious and tourism studies. Unlike geography of religion, focused on the study of the distribution of material manifestations of the spiritual sphere (sacred structures, religious denominations, communities, etc.), sacred geography – as noted by L.T. Shevchuk – has a broader scope, related to the sense of the sacred by a particular person, group of people, or society. Furthermore, she emphasized the primacy of the sacred over religious: “...before religions with their postulates and norms, there already existed a sacred world of a human, an ethnos” (Shevchuk, 1999). According to L.T. Shevchuk, objects of sacred geography consist of “humans, their sacred world, religious behavior, social environment, and religious organizations, natural and social environment, and places of worship, social doctrine of church – geospatial forms of sacred elements, including elements of religion as a complex of objects and phenomena, their mythology, content, genesis, dynamics, factors, and laws of their formation and functioning” (Shevchuk, 2007). As concrete actual objects of sacred geography, O.I. Shablii considered geospatial forms of this organization, focusing in particular on their morphology, scope, genesis, dynamics, factors, and laws governing their formation and functioning (Shablii, 1994).

The sacred sphere is a component of the geospace system, composed of the objects that have special spiritual, religious significance for, or are considered holy by a certain culture, religion, ethnos, or group of people. All sacred objects are characterized by dualism, that is, the presence of a material (physical) component and manifestation of a spiritual component. Sacred objects are “cores” and “centers” in the formation of the structure of a sacred space and sacred landscapes. Such objects can be of natural and natural-anthropogenic or anthropogenic genesis. The natural and natural anthropogenic group comprises objects

of living (century-old trees, floristic landscapes) and inanimate nature (mountain tops, rock formations, hydroobjects, grottos). The anthropogenic group includes wooden and stone churches, monasteries, *kostels*, and synagogues. Ivano-Frankivsk Oblast is one of the most presentable regions of Ukraine by the level of preservation and development of sacred space. Sacred objects play not only a religious and cultural role, but also serve as markers of ethnocultural identity and tourist-recreation attractiveness of the territory.

Modern approaches to the management of territorial development are based on complex information systems of modeling the development of natural, social phenomena and processes, where a decisive role is played by geoinformation systems (GIS) as a tool of accumulation, processing, and analysis of spatial information. One of the integral topics of interaction of objects of the sacred sphere and tourist-recreation activity is modeling cornerstone relations, which can help to understand and manage this interaction so as to preserve sacred monuments, satisfy the needs of tourists and recreationists, and also boost regional economy. In this context, the method of cluster analysis is an effective tool to detect spatial-functional groups of sacred objects of Ivano-Frankivsk Oblast, which can be a foundation for the development of an effective model of sacred-geography zoning in the context of sustainable development of the region.

In scientific studies on the creation of tourist clusters, special attention is paid to local aspects of this territorial formation and its positive effects on the socioeconomic development for particular territories. From the geographical standpoint, the formation of tourist clusters was actively studied by A.B. Haiduk (2006), who argued the use of the cluster approach in the sphere of tourism, and extensively analyzed the key aspects of the formation and functioning of integrated tourist enterprises in Ukraine. Focusing on the tourist cluster, L.I. Hontarzhevskaya (2006) justified its introduction as a form of organizing tourist activities within national industries from scientific and practi-

cal perspectives. O. Topchiiev, V. Sych, V. Yavorska, K. Kolomiets, I. Hevko, O. Murkalov, N. Smochko (2023) considered the use of methods of qualimetrics for assessments of recreation-tourist potential on the example of ecotourist cluster. L.M. Tomanevych (2005) focused on tourist-recreation complexes, conducting a theoretical analysis of the economic mechanism by which they operate in Ukraine and developing practical recommendations for its improvement. Also, it is worth mentioning the monograph by N.V. Korzh and D.I. Basiuk (2017), which in great detail considers the cluster approach in the management of tourist destinations. A.P. Holod, O.P. Izhevskaya, and O.I. Korkuna substantiate the conceptual grounds for the formation and scientific analysis of clusters of hospitality industry, proposing the following methodological approaches to developing a cluster model at a regional level: systemic approach, grounds for innovative and spatial development, principles of integrability, resource orientation, socialization, and self-organization (Holod, Izhevskaya, & Korkuna, 2019).

The foreign reports have been focused on the use of cluster analysis for processing geochemical data (Zhou, Zhou, Wang, Yang, & Wang, 2018), evaluation of the resources (Nwaila, Rose, Frimmel, & Ghorbani, 2025), classification of geo-references time series (GTS) (Wu, Cheng, Zurita-Milla, & Song, 2020), and development of geoclusters for the planning of energy systems (Kuster, Hippolyte, Rezugui, & Mourshed, 2019), which confirms the effectiveness of using the method in natural-sciences studies.

The objective of the study was clustering the sacred objects of Ivano-Frankivsk Oblast by the means of mathematical-statistical methods to validate the scheme of sacred-geography zoning of the region.

Methods of research

During the work, we used a broad spectrum of general scientific, interdisciplinary, and special methods. In particular, we analyzed the literature sources (to analyze the clustering principles), and carried out geodata analysis (for spatial analysis of the arrangement of sacred objects within Ivano-Frankivsk Oblast), cluster analysis (to study sociogeographic objects in a unity and integrity of interrelated elements), and zoning (for zoning of the study territory according to the spatial positioning of sacred objects).

Results and analysis

Clustering (or cluster analysis) is a process of partitioning a set of data or objects into meaningful subgroups called clusters. Those clusters promote a

better understanding of the natural grouping or structure of this set of data. Clustering – as a method of grouping multidimensional objects – is based on presenting certain observations with points of geometric space, with subsequent classification of these points into groups (Murray, & Estivill-Castro, 1998).

The data associated with location is called “spatial data”, which can be represented as objects geometrically shaped as points, lines, or polygons and as a set of coordinates defined by a Coordinate Reference System (CRS) (Zein, Dowaji, & Al-Khayatt, 2023).

Therefore, cluster analysis is the task of partitioning a given sampling of objects into subsets that do not overlap and are called clusters. Each cluster is composed of objects with similar parameters, whereas objects of different classes quite substantially vary among one another. Clustering is broadly used in different scientific disciplines about data (including geodata) (El-Haj, Alshamsi, & Aldahan, 2023; Guo, Peuquet, & Gahegan, 2003).

The use of geographic coordinates allows for the consideration of mutual arrangement of objects in geographic space and the topology of their relations. Correspondingly, the zoning of a territory based on mathematically substantiated data can be performed. In this context, we conducted clustering (division into groups) of the class of natural and natural-anthropogenic sacred objects and the class of anthropogenic sacred objects into groups in which the objects are quite compactly arranged around some centers.

As parameters, we chose coordinates of the groups of natural and natural-anthropogenic and anthropogenic objects, and as the clustering method we employed k-means. The k-means algorithm is suitable for processing spatial data and can be used as a basis for its partitioning. This method is one of the commonest algorithms of cluster analysis, in which objects are grouped around centroids, and the criterion is the distance between the cluster's objects and their centroid. Points belonging to one cluster are as close as possible to one another and as far as possible from points of other clusters.

The k-means method aims at minimizing the mean quadratic distance between the points in one cluster. The main idea of the k-means method lies in identifying clusters in a way that minimizes the total variation between the clusters (that is the total variation within one cluster). There are several algorithms for this method, but the standard algorithm determines the total variation within a cluster as a sum of squared Euclidean distances between the elements and the respective centroid:

$$W(C_k) = \sum_{x_i \in C_k} (x_i - \mu_k)^2, \tag{1}$$

where x_i – point of the data that belongs to cluster C_k , and μ_k – mean value of the points assigned to cluster C_k . Each observation x_i is assigned to the set cluster in such a way that the sum of squared distances from the observation to its assigned cluster center μ_k is minimized.

The k-means method implies that the number of clusters is known in advance. As a criterion, two characteristics of the method were considered: inertia of k-means (with the elbow analysis) and the silhouette score. Inertia is a sum of squared distances between each object and the centroid (mean value) of the cluster to which it belongs. For each cluster, separate inertia is quantified, and then all those values are summed to obtain the total inertia of the model. Inertia is used to determine the level of the cluster’s compactness. The objective is to minimize the inertia, but it usually declines with increase in the number of clusters. The silhouette analysis measures how similar objects are within one cluster compared with other clusters. It is calculated for each object and is expressed in the range from -1 to 1. Value closer to 1 indicates that the object is well matched to its own cluster and poorly matched to the other clusters. Value closer to 0 means that the object is close to the boundary between two clusters. Value closer to -1 indicates that the object is remote from its own cluster and well matched to the other clusters. The silhouette score helps identify how well are the objects positioned in clusters. Usually, k value with the highest average silhouette is chosen, because it indicates the best quality of clustering.

To perform the clustering, two software programs were written using the high-level algorithmic language Python: one for introducing the data and the

second for clustering. The clustering was performed in the integrated development environment PyCharm, in which – using the tools of the Python programming language – we conducted a spatial analysis of the sacred objects, assessed the inertia and silhouette of the clusters, and presented the visualized models (Fig. 2; fig. 4-6; fig. 8-10).

The stages of the clustering of sacred objects of Ivano-Frankivsk Oblast for the purpose of sacred-geography zoning are presented in Table 1.

Clustering of the groups of natural and natural-anthropogenic sacred objects. To choose an optimal number of clusters, we conducted clustering of 69 natural and natural-anthropogenic sacred objects of Ivano-Frankivsk Oblast with a number of clusters ranging from 2 to 9. Figure 1 presents the estimates.

As seen in the figure, the optimal number of clusters is three. Selecting 7, 8, and 9 clusters leads to the fragmentation of clusters (a number of objects in some of them is low). Figure 2 presents the result of clustering for three clusters.

In Fig. 2, using a cross mark, three cluster centers are indicated. Their coordinates are as follows: N 48°58’19”, E 24°49’47”; N 48°49’09”, E 24°07’10”; and N 48°15’15”, E 24°51’15”. The points corresponding to these centers are located near the Uzyn village of Ivano-Frankivsk District, between the villages Letsivka and Ripne of Kalush District, and near the Shepit village of Kosiv District.

Clustering of the group of anthropogenic sacred objects. To select an optimal number of clusters, we performed clustering of 614 anthropogenic objects of Ivano-Frankivsk Oblast, with the number of clusters from 2 to 9. As a criterion, we considered two characteristics of the method: inertia of k-means and the silhouette score. Figure 3 presents the estimates. The figure demonstrates that the optimal number of clusters is 4: From this value, the inertia starts decreasing

Table 1. Stages of the clustering of sacred objects of Ivano-Frankivsk Oblast

● Collection and preparation of the data	The first step was the collection of geographic coordinates of the objects. These data were obtained using the GPS Maps system and the GoogleEarth app for identifying location.
● Selection of similarity metrics	The similarity metrics defines how the objects are compared among one another. We used the metrics that takes into account geographic distances (Euclidean distance for geographic coordinates).
● Selection of the number of clusters (k)	Determining the number of clusters is the key step. To validate the clustering quality depending on the number of clusters, we used two characteristics: inertia of k-means and silhouette score.
● Clustering	At this step, k-means clustering per se is performed.
● Evaluation and analysis of the results	To understand the geographic patterns and features of the formation of clusters, we identified the boundaries of clusters, evaluated the results were and analyzed what objects were included in each cluster and how are they positioned on the map.
● Zoning	Based on the results of clustering, sacred-geography districts were determined.

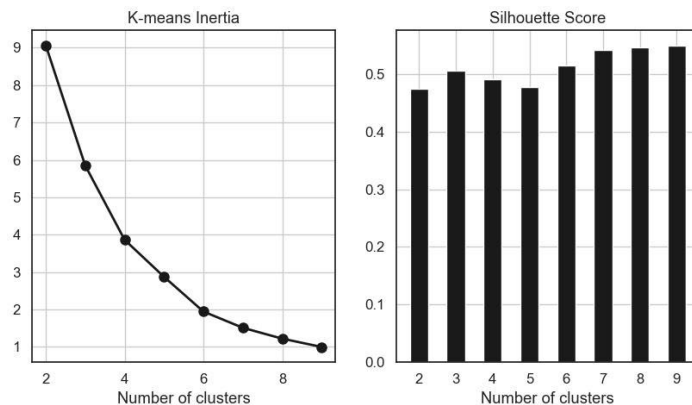


Fig. 1. Relationships between the inertia and silhouette and the number of clusters (natural and natural-anthropogenic objects)

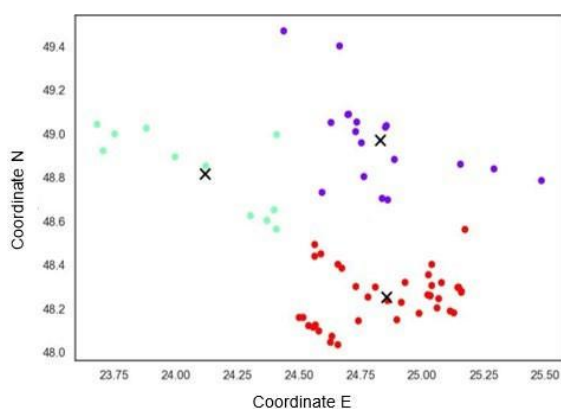


Fig. 2. Visualization of the partition of the natural and natural-anthropogenic sacred objects of the study area into 3 clusters

at lower rates. Figures 4, 5, and 6 show the results of clustering for two, three, and four clusters.

In Fig. 4, using a cross symbol, we indicated 2 centers of the clusters. Their coordinates are as follows: N 48°34'13", E 25°06'17" and N 49°01'39", E 24°24'53". To these centers, the following settlements correspond: the Kalush city and the Yasinky village of Kolomyia District.

In Fig. 5, a cross mark demonstrates 3 centers of clustering, with the following coordinates: N 48°32'09", E 25°08'00" (the Tseniava village, Kolomyia District); N 48°54'37", E 24°06'10" (the Yasenovets village, Kalush District); and N 49°04'01", E 24°38'37" (the Viktoriv village of Ivano-Frankivsk District).

Figure 6 demonstrates the visualization of the partitioning of the sacred anthropogenic objects into 4 clusters. Coordinates of the centroids are as follows: N 48°31'06", E 25°14'16" (the Krynychky village, Kolomyia District); N 49°14'47", E 24°36'03" (the Demianiv village, Ivano-Frankivsk District); N 48°55'46", E 24°05'53" (the Nyzhnii Strutyn village of Kalush District); and N 48°44'41", E 24°44'18" (the Vynohrad village, Kolomyia District).

Clustering of the groups of natural and natural-anthropogenic and anthropogenic sacred objects of Ivano-Frankivsk Oblast. To choose an optimal number of clusters, we performed clustering of 683 natural and natural-anthropogenic and anthropogenic sacred objects of Ivano-Frankivsk Oblast, with the number of clusters from 2 to 9. Figure 7 demonstrates the estimates.

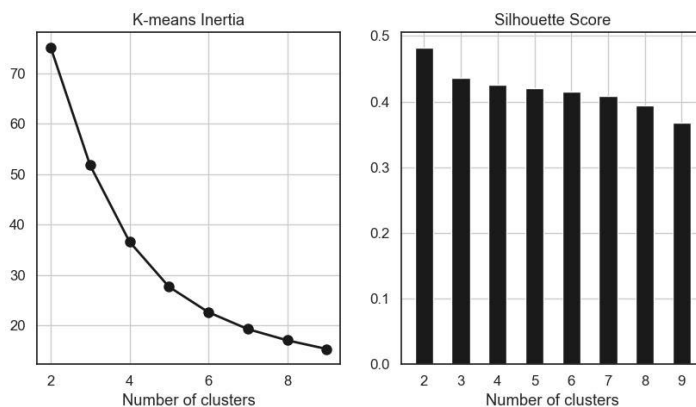


Fig. 3. Relationships between the inertia and silhouette on the number of clusters (anthropogenic sacred objects)

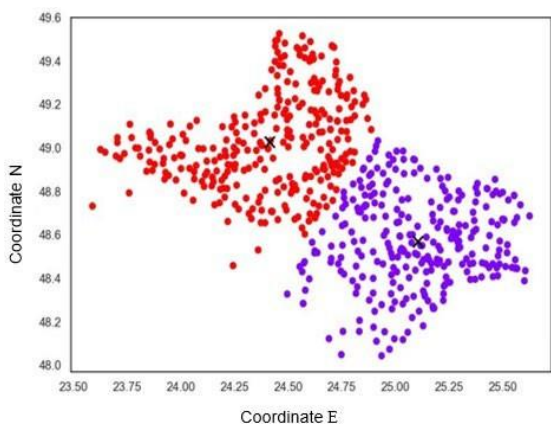


Fig. 4. Visualization of the partition of the anthropogenic sacred objects into two clusters

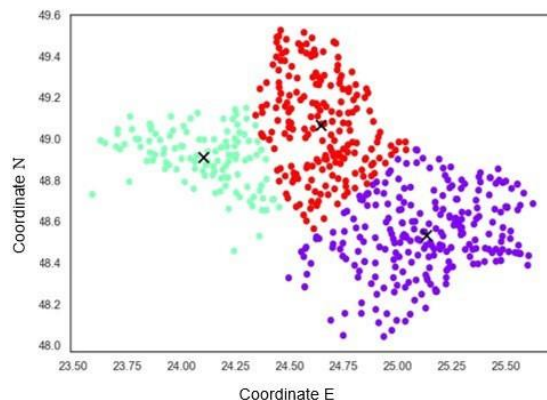


Fig. 5. Visualization of the partition of the anthropogenic sacred objects into 3 clusters

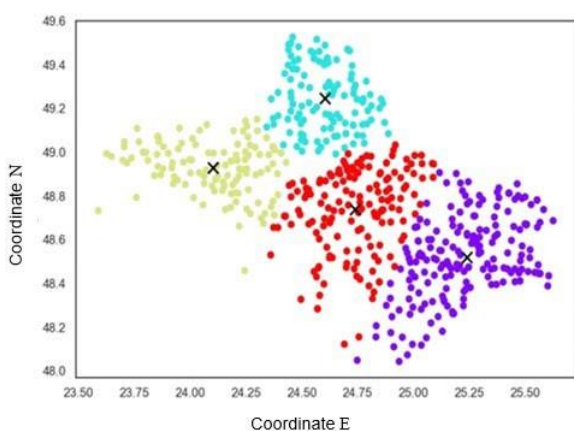


Fig. 6. Visualization of the partition of the considered anthropogenic sacred objects into 4 clusters

As we see in the figure, the optimal number of clusters is 5, because the inertia and silhouette plots at this number of clusters indicate the best result. Figures 8 and 9 show the results of clustering of all sacred objects of Ivano-Frankivsk Oblast for two and three clusters.

In Fig. 8, using a cross mark, 2 centers of the clusters are indicated. Their coordinates are as follows: N 48°32'05.2", E 25°04'35.5" and N 49°01'17.0", E 24°25'03.2". These centers are the cities Kolomyia and Kalush.

Figure 9 depicts the division of all sacred objects into 3 clusters, with the centroids indicated with a cross mark. Their coordinates are as follows: N 49°04'08.8", E 24°38'53.1"; N 48°54'05.5", E 24°06'07.6"; and N 48°30'10.8", E 25°05'42.2". To those centers, the following settlements correspond: the Viktoriv village, Ivano-Frankivsk District; the Yasenovets village, Kalush District; and the Kornych village, Kolomyia District.

Figure 10 visualizes the unification of the objects in 5 clusters, with the centroids indicated with a cross mark and corresponding to the following coordinates:

- N 48°50'03.3", E 24°45'32.7" (Bratkivtsi village, Ivano-Frankivsk District);
- N 48°54'57.7", E 24°06'26.4" (Verhni Strutyn village, Kalush District);

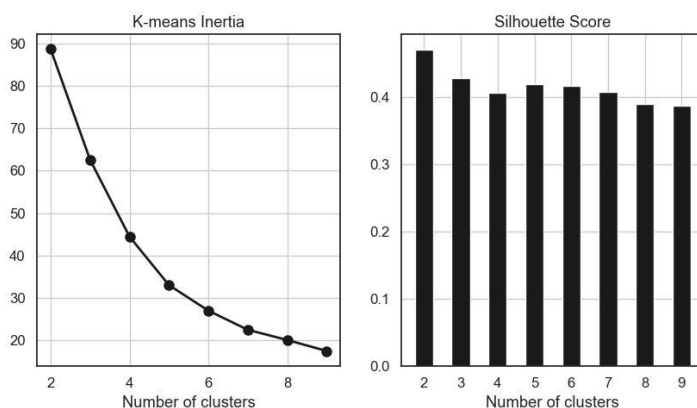


Fig. 7. Relationships between the inertia and silhouette and the number of clusters (all the sacred objects)

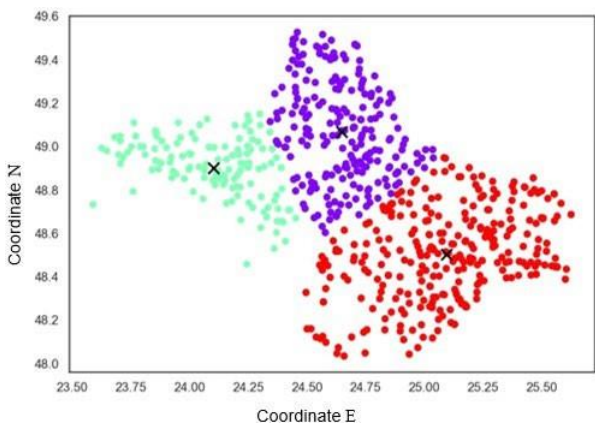


Fig. 8. Visualization of the partition of the groups of natural and natural-anthropogenic and anthropogenic sacred objects into two clusters

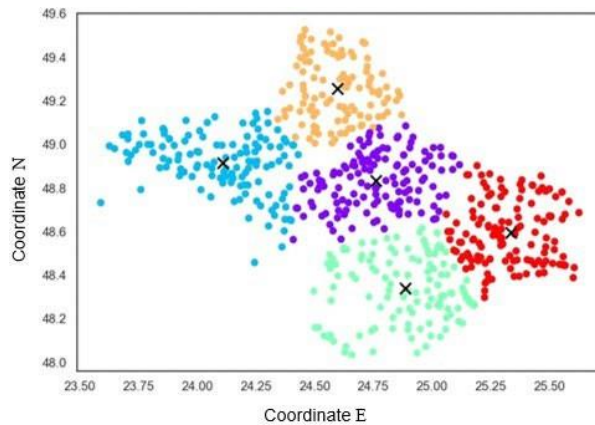


Fig. 9. Visualization of the partition of the natural and natural-anthropogenic and anthropogenic sacred objects into three clusters

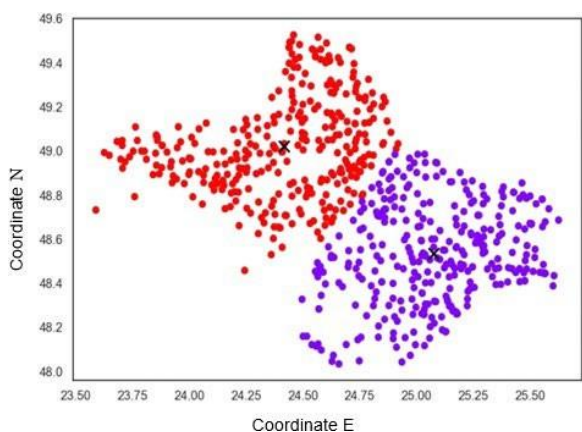


Fig. 10. Visualization of the partition of the natural and natural-anthropogenic and anthropogenic sacred objects of the studied territory into 5 clusters

- N 48°20'20.5", E 24°53'11.9" (Prokurava village, Kosiv District);
- N 49°15'24.1", E 24°35'44.9" (Vyhivka village, Ivano-Frankivsk District);
- N 48°35'38.9", E 25°20'10.5" (Slobidka village, Kolomyia District).

Based on the clustering, we performed a sacred-geography zoning of the territory of Ivano-Frankivsk Oblast (figures 11-12), where a certain district corresponds to each cluster. Boundaries of the clusters (Fig. 11) correspond to the boundaries of the districts. Thus, within the oblast, 5 sacred-geography districts were designated: Opilskyi, Boikivsko-Hutsulskyi, Opilsko-Pokutskyi, Pokutskyi, and Hutsulsko-Pokutskyi.

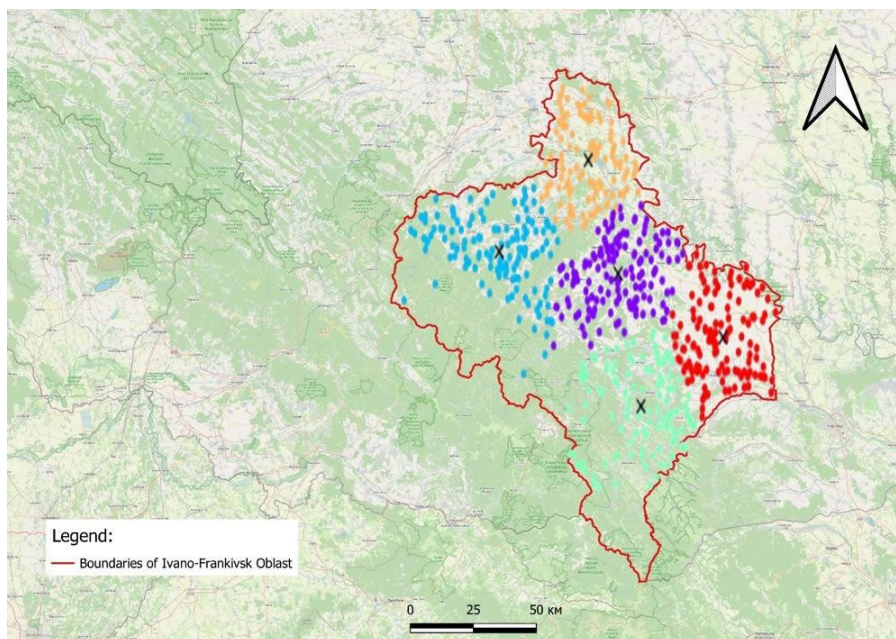


Fig. 11. The map of the clusters, developed in the PyCharm integrated environment

For substantiated districts, we made a detailed geographic characteristics, the features of which are key for organizing tourist-recreation activity. The results of the sacred-geography studies of the designated districts are presented in Table 2.

Conclusions

The use of the method of k-means cluster analysis in the studies of sacred objects of Ivano-Frankivsk Oblast allowed us to conduct a spatially substantiated grouping of the objects based on geographic coordinates. The use of such a parameter allows reflecting an actual arrangement of the objects in the area, which is key for territory zoning. The objects within one clus-

ter are arranged as compactly as possible around their centroid. They reflect the natural geographic groups of sacred objects, which allows developing a zoning scheme for the study territory based on mathematically verified data.

The results of the clustering can be used in practice for the protection of historical and cultural relics, and also the organization and management of tourist-recreation industry, particularly in planning of routes, development of infrastructure, planning and management of tourist flows, and marketing and advertizing. Similar studies of sacred landscape complexes using the method of cluster analysis can be performed for other regions of Ukraine and abroad.

Table 2. Sacred-geography characteristic of the districts

Name of the district	Площа км ² Area, km ²	Total density of the sacred objects	Density of natural and natural-anthro- pogenic objects	Density of anthropogenic objects	Ratio of the natural and an- thropogenic
1. Opilskyi sacred-geography district	1,687	0.07706	0.003557	0.073503	1:20
2. Boikivsko-Hutsulskyi sacred-geography district	4,292	0.03285	0.002562	0.030289	1:13
3. Opilsko-Pokutskyi sacred-geography district	2,339	0.06587	0.004275	0.061564	1:10
4. Pokutskyi sacred-geography district	2,162	0.05597	0.001388	0.054579	1:39
5. Hutsulsko-Pokutskyi sacred-geography district	3,460	0.03958	0.01185	0.027745	1:2

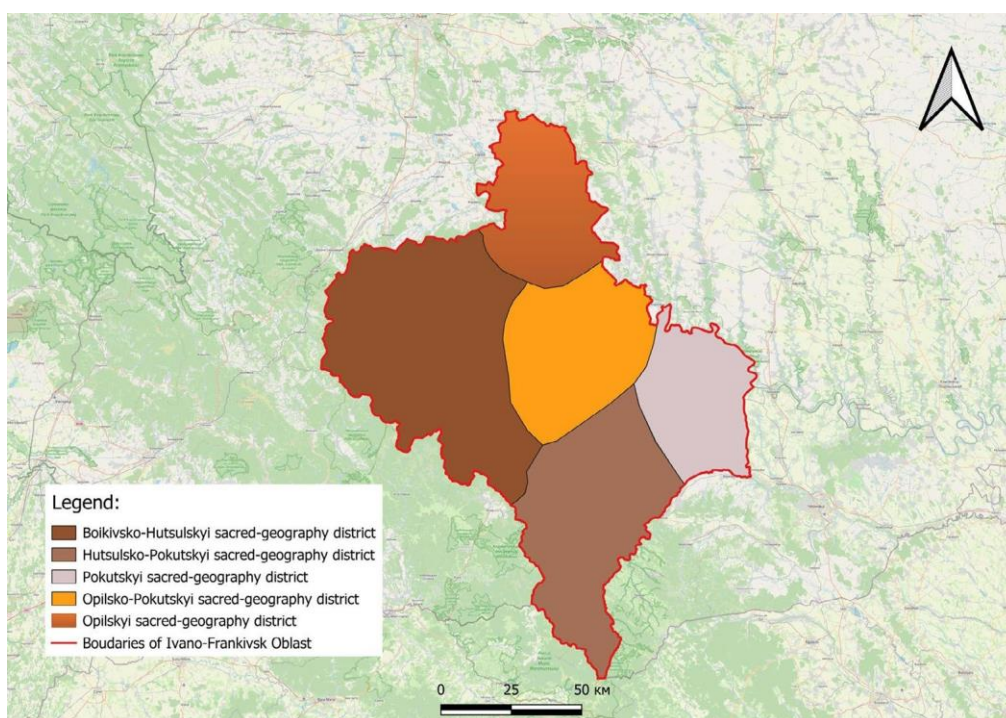


Fig. 12. The map of the sacred-geography zoning of Ivano-Frankivsk Oblast (according to our study)

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