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RESEARCH TECHNOLOGIES OF TEACHING IN HIGHER EDUCATION: APPLYING MULTIDIMENSIONAL ANALYTICAL APPROACHES TO THE STUDY OF HYDRONYMY OF WESTERN KAZAKHSTAN

The relevance of the research is determined by the need to develop new research methods and technologies for teaching higher education in the field of didactics of teaching philological sciences, including linguistics In particular, the article considers a research methodology for teaching the use of modern interdisciplinary methods for analyzing the hydronyms of Kazakhstan based on the material of the Western region. Hydronyms act as important markers of the features of the natural landscape, cultural memory, and historical processes, but traditional descriptive and etymological approaches do not fully reveal their multilayered structure.Deeper interpretation requires combining cognitive, semantic, and geoinformation methods, which can be effectively integrated into the training of bachelor's, master's, and doctoral students.

The purpose of this work is to generalize a research -based teaching methodology in linguistics by systematizing contemporary approaches to cognitive, semantic, and cartographic modeling of regional hydronymy. The article shows the potential of their integration within a single analytical model and the potential of research teaching methods. The possibilities of using cognitive analysis to reconstruct conceptual frames, semantic clustering, and to identify motivational groups in order to identify areal patterns and spatial structures are considered.It is emphasized that such studies should be grounded in materials from topographic maps, archival sources, published works, and field data.

The study illustrates that combining cognitive models with GIS visualization makes it possible to uncover hidden relationships between hydronyms and landscape characteristics, while semantic methods differentiate Turkic, Iranian, and other motivational layers. Spatial modeling confirms the key role of river systems in shaping the region's toponymy. The scientific novelty of the work lies in substantiating a research-based learning technology built on the integration of cognitive, semantic, and cartographic approaches for multidimensional analysis of the target units. The results can be used in courses for training learners at different levels and more broadly in linguistics, geography, and cultural studies, as well as in developing regional cartographic resources, systematizing toponymic data, and research aimed at preserving linguistic heritage.

Keywords: hydronymy, Western Kazakhstan, cognitive analysis, toponymic motivation, modern educational technologies.

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Жоғары оқу орындарындағы оқытудың зерттеушілік технологиялары: Батыс Қазақстан гидронимиясын зерттеуде көпөлшемді аналитикалық тәсілдерді қолдану

Зерттеудің өзектілігі филология ғылымдарын, оның ішінде лингвистиканы оқытудың дидактикасы саласында жоғары білім беруді оқытудың жаңа зерттеу әдістері мен технологияларын әзірлеу қажеттілігімен анықталады. Атап айтқанда, мақалада Батыс өңірінің материалында Қазақстанның гидронимдерін талдау үшін заманауи пәнаралық әдістерді қолдануды оқытудың зерттеу әдістемесі қарастырылған. Гидронимдер табиғи ландшафт ерекшеліктерінің, мәдени жадының және тарихи процестердің маңызды белгілері ретінде әрекет етеді, бірақ дәстүрлі сипаттамалық және этимологиялық тәсілдер олардың көп қабатты құрылымын толық ашуға мүмкіндік бермейді. Терең интерпретация когнитивтік, семантикалық және геоақпараттық әдістерді ұштастыруды талап етеді және бұл тәсілдер студенттерді, магистранттарды, докторанттарды оқытуда табысты қолданылуы мүмкін.

Жұмыстың мақсаты – өңір гидронимиясын когнитивтік, семантикалық және картографиялық модельдеу бағытындағы қазіргі заманғы тәсілдерді жүйелеу арқылы тілтаным саласындағы зерттеушілік оқыту әдістемесін жинақтау. Мақалада аталған тәсілдерді бірыңғай аналитикалық модель аясында біріктіру әлеуеті және зерттеушілік оқыту әдістерінің мүмкіндіктері көрсетіледі. Когнитивтік талдауды концептуалдық фреймдерді реконструкциялауда, семантикалық кластерлеуді мотивациялық топтарды айқындауда, сондай-ақ кеңістіктік паттерндер мен құрылымдарды анықтауда қолдану жолдары сипатталады. Білім алушылар үшін мұндай зерттеулердің топографиялық карталар материалдарына, архивтік дереккөздерге, жарияланған еңбектерге және далалық мәліметтерге негізделуі маңызды екені ерекше атап өтіледі.

Зерттеу нәтижелері когнитивтік модельдер мен ГИС-визуализацияны ұштастыру гидронимдер мен ландшафттық сипаттамалар арасындағы жасырын байланыстарды анықтауға мүмкіндік беретінін, ал семантикалық әдістер түркітілдес, ирантілдес және өзге де мотивациялық қабаттарды ажырататынын көрсетеді. Кеңістіктік модельдеу өңір топонимиясын қалыптастыруда өзен жүйелерінің шешуші рөлін дәлелдейді. Жұмыстың ғылыми жаңалығы – ізделінетін бірліктерді көпөлшемді талдауға арналған когнитивтік, семантикалық және картографиялық тәсілдерді интеграциялауға негізделген зерттеушілік оқыту технологиясын теориялық тұрғыдан негіздеуінде. Алынған нәтижелер әртүрлі деңгейдегі білім алушыларды даярлауға бағытталған пәндерде, сондай-ақ лингвистикада, географияда, мәдениеттануда, өңірлік картографиялық ресурстарды әзірлеуде және топонимиялық деректерді жүйелеуде, сонымен қатар тілдік мұраны сақтау мәселелеріне арналған зерттеулерде қолданылуы мүмкін.

Түйін сөздер: гидроним, Батыс Қазақстан, когнитивті талдау, топонимикалық мотивация, заманауи білім беру технологиялары.

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Исследовательские технологии обучения в высшем образовании: применение многомерных аналитических подходов к изучению гидронимии Западного Казахстана

Актуальность исследования определяется необходимостью разработки новых исследовательских методов и технологий обучения высшего образования в области методики преподавания лингвистики. В частности, в статье рассмотрена исследовательская методика обучения применения современных междисциплинарных методов для анализа гидронимов Казахстана на материале Западного региона. Гидронимы выступают в качестве важных маркеров особенностей природного ландшафта, культурной памяти и исторических процессов, однако традиционные описательные и этимологические подходы не позволяют в полной мере раскрыть их многослойную структуру. Глубокая интерпретация требует сочетания когнитивных, семантических и геоинформационных методов, которые можно успешно использовать в обучении студентов, магистрантов, докторантов. Цель настоящей работы – обобщить исследовательскую методику обучения в области языкознания через систематизацию современных подходов к когнитивному, семантическому и картографическому моделированию гидронимии региона. В статье показан потенциал их интеграции в рамках единой аналитической модели и потенциал исследовательских методов обучения. Рассматриваются возможности использования когнитивного анализа для реконструкции концептуальных фреймов, семантической кластеризации, для определения мотивационных групп с целью выявления площадных паттернов и пространственных структур. Обучающимся важно знать, что подобные исследования должны быть основаны на материалах топографических карт, архивных источниках, опубликованных работах и полевых данных. В работе наглядно представлено, как анализ показывает, что сочетание когнитивных моделей и ГИС-визуализации позволяет выявить скрытые связи между гидронимами и ландшафтными характеристиками, в то время как семантические методы различают тюркоязычные, ираноязычные и другие мотивационные слои. Пространственное моделирование подтверждает ключевую роль речных систем в формировании топонимии региона. Научная новизна заключается в обосновании исследовательской технологии обучения, связанной с интеграцией когнитивного, семантического и картографического подходов для многомерного анализа искомых единиц. Полученные результаты могут быть использованы в дисциплинах по подготовке обучающихся разного уровня, в целом, лингвистике, географии, культурологии, при создании региональных картографических ресурсов и систематизации топонимических данных, а также в работах, направленных на сохранение лингвистического наследия.

Ключевые слова: гидроним, Западный Казахстан, когнитивный анализ, топонимическая мотивация, современные образовательные технологии.

Introduction

The development of research-oriented teaching technologies for higher education has become an increasingly important issue in contemporary pedagogical practice, particularly in the didactics of linguistics and language studies. At the master's and doctoral levels, learning outcomes are no longer limited to the assimilation of theoretical knowledge; rather, they involve the formation of advanced research competencies, including problem formulation, methodological justification, corpus construction, critical source analysis, data verification, analytical modeling, and academic writing. In this context, research-based learning (RBL) and inquiry-driven pedagogies provide a productive framework for training future researchers and university lecturers, as they enable a transition from reproductive learning to the design and implementation of full-scale empirical investigations grounded in authentic linguistic material. This shift is especially relevant for onomastics and toponymy, where the object of study is inherently interdisciplinary and demands integration of linguistic, historical, cultural, and spatial-analytical perspectives.

Within the strategic study of the onomastic space of the Republic of Kazakhstan, the improvement of scientific and analytical work on hydronyms constitutes and the implementation of its results in the educational process one of the key priorities. Comprehensive investigation of water names is essential for reconstructing historical and cultural processes, identifying nomination patterns, and clarifying the semantic, cognitive, and cartographic parameters of regional toponymy (Smagulov, 2022). The hydronymy of Western Kazakhstan represents a particularly complex system in which linguistic, ethnocultural, natural-geographical, and historical factors intersect. Consequently, effective research of this onomastic domain requires modern analytical approaches that combine cognitive interpretation, semantic modeling, and geoinformation technologies. This is important for the development of onomastic knowledge and the teaching of new research approaches in universities. The study of hydronyms in universities is necessary for a deep understanding of the history, culture, ethnogenesis of peoples and the formation of national identity.

So, for example, the specificity of Western Kazakhstan hydronymy is shaped by the diversity of natural conditions, the multilayered nature of linguistic influence, and the region's extensive territorial scale. These features are especially evident in the analysis of major hydrographic units such as *Zhaiyk* (*Ural*), *Oyl*, *Sagyz*, *Ilek*, *Shagan*, *Derkol*, *Karaozen*, and *Saryozen*, which constitute the structural framework of the regional drainage network. The naming patterns of these water bodies reveal intersections of Turkic, Slavic, Iranian, and Finno-Ugric influences, thereby underscoring the need for an interdisciplinary research design. Unlike traditional descriptive or purely etymological accounts, a contemporary analysis of regional hydronyms should incorporate the interpretation of naming motivation, the identification of latent semantic relations, and the detection of spatial regularities in the distribution of water objects (Eginbayeva, 2022). These tasks require flexible research strategies capable of accounting for semiotic, historical, and landscape parameters, which are important for expanding students' learning competencies.

A further dimension concerns the role of natural and climatic conditions in the emergence and preservation of hydronyms. The instability of hydrological processes, variability of channels, and seasonality of water regimes can reshape toponymic systems over time, creating challenges for diachronic and synchronic interpretation. This, in turn, necessitates adaptive analytical procedures capable of identifying both change dynamics and stable elements within the hydronymic inventory (Granata & Di Nunno, 2025). Equally significant is the interaction of multiple linguistic strata typical for contact zones where Turkic, Slavic, Iranian-speaking, and Finno-Ugric traditions have historically overlapped. Such stratification produces a complex motivational system that requires analytical instruments able to differentiate structural and semantic levels, as well as to reveal internal regularities in name distribution. Accordingly, researchers must consider diverse motivational types-natural-geographical, functional, anthropocentric, and cultural-historical – when interpreting hydronym formation.

The digitalization of humanities research opens additional opportunities for hydronym analysis through the use of cartographic services, computational tools, and semantic clustering methods. These approaches facilitate the structuring of large datasets, the detection of hidden associations, and the modeling of spatial configurations of hydronyms – capabilities that are particularly valuable for territories with low population density and complex geography. Regional differences in the hydronymic system of Western Kazakhstan are conditioned by ethnocultural features, local landscapes, historical routes, and settlement patterns, which calls for differentiated research models sensitive to the spatial logic of nomination and the historical evolution of regional toponymy.

Importantly, the analytical framework outlined above has direct educational implications for postgraduate training in linguistics. Integrating cognitive analysis, semantic clustering, and GIS-based visualization into research-oriented coursework enables students to work with authentic data sources (topographic maps, archival records, published studies, and field materials), develop methodological literacy, and acquire transferable competencies in digital linguistics and spatial humanities. In this sense, the study of Western Kazakhstan hydronymy functions not only as a scholarly task but also as a productive educational platform for forming advanced research skills and interdisciplinary thinking. The present study therefore aims to substantiate and systematize a research-based teaching methodology in linguistics by integrating cognitive, semantic, and cartographic approaches into a unified multidimensional analytical model for hydronym investigation.

1.1 The purpose of the study

To generalize a research-based teaching methodology in linguistics by systematizing contemporary approaches to the cognitive, semantic, and cartographic modeling of the region's hydronymy.

1.2 Research objectives

- To summarize the research methods used in hydronym studies, identify their limitations, and translate these findings into an educational technology.

- describe the key scientific gaps in the modern literature;

- consider the prospects of integrating cognitive and semantic approaches with mapping;

- provide examples of analytical models used in scientific research;

- to show the directions of further development of interdisciplinary analysis of hydronyms.

Literature review

An analysis of the works (Abdulina, A. G., 2018) shows that the existing methods of studying hydronyms are insufficient for a deep disclosure of their cognitive and spatial characteristics. Despite the available research (Bekenova, G. Sh., 2022) there are no comprehensive models combining cognitive analysis, semantic methods and cartographic modeling. This leads to the fact that a significant part of the patterns of the hydronymic system remains undetected. An analytical review and generalization of the main results of onomastic research allows us to note significant successes in Kazakh onomastics (Madiyeva, 2010).

Traditional approaches based only on etymological and semantic analysis (Nichols, 2025; Avdić, 2023) do not take into account the multidimensionality of the hydronymic material and do not allow to identify complex relationships between meaning, form and spatial distribution. Methods that work simultaneously with several target parameters are needed: the motivational structure of hydronyms (Voutilainen, 2024; Kurilova, 2023), their semantic groups (Kumar, 2021) and areal characteristics (O'Reilly, 2023).

The national cognitive base of the people includes archetypical ideas and practical experience of exploring the surrounding environment, encoded in the phytomorphic, zoomorphic, somatic, and spatial codes, which are linked to information about categorisation of the whole Kazakh life space since ancient times (Rysbergen K. et al., 2024).

In this generalizing study, it is proposed to consider the potential of a hybrid approach combining cognitive modeling, semantic clustering and cartographic methods. The approach is analyzed as a promising direction that makes it possible to identify stable structures, identify typical nomination models, and reconstruct the spatial logic of the formation of the region's hydronymy.

To systematize the existing approaches, a comparison of the methods of analysis of hydronyms presented in the literature was carried out. Table 1 shows the main differences between the common types of studies.

Table 1
Comparative analysis of hydronym research methods

Approach	Advantages	Limitations
Traditional descriptive analysis	Ease of use, accessibility	Does not reveal hidden connections, low analytical depth
Etymological analysis	Defines the origin and motivation	It does not show spatial patterns
Semantic modeling	Groups names by semantic parameters	Requires structured data
Clusterization	Identifies hidden typological groups	Depends on the correct configuration of the model
GIS mapping	Shows spatial connections	Does not reveal cognitive models
Hybrid methods (cognitive analysis + clustering + GIS)	High information content, multidimensional	Complexity of implementation, high labor intensity

Source / Note: This table was compiled by the authors based on the analysis of materials.

Based on the literature analysis, the following scientific gaps have been identified that require further consideration:

1. Insufficient integration of semantic, cognitive and spatial characteristics of hydronyms in a single model;
2. Limited use of semantic modeling methods in conjunction with GIS approaches;
3. a small number of papers using cluster algorithms to identify hidden typological groups;
4. Insufficient elaboration of approaches linking cognitive frames with areal structures.

Materials and methods

Participants and educational context. The proposed cognitive–semantic–cartographic methodology for hydronym analysis was implemented as part of regular course-based instruction (training) at two higher education institutions in Kazakhstan. At Kh. Dosmukhamedov Atyrau University (Department of Kazakh Language and Literature), *25 students* studied and applied the methodology within the course "Word formation of the modern Kazakh language". During this course, there are lectures where students gain knowledge about the word-formation nature of hydronyms, the specifics of lexico-semantic groups and the motivation of hydronyms.

At Al-Farabi Kazakh National University (Department of Turkic Studies and Language Theory), the same methodology was taught to *10 doctoral (PhD) students* within the course "Language, consciousness and national mentality", "General Linguistics: Structure and Semantics" In all cohorts, training followed a unified sequence of learning activities: (i) concise theoretical sessions on semantic motivation, cognitive frames, and spatial parameters of hydronyms; (ii) guided practical work on annotating hydronyms with semantic and motivational indicators and constructing feature vectors $H_i = [s_i, m_i, t_i, x_i, y_i]$; (iii) cluster-based typological grouping and interpretation; and (iv) GIS-supported mapping to identify areal patterns and relate linguistic features to landscape and river-network structures.

Onomastic studies of recent decades in the Republic of Kazakhstan show the need to move from a fragmentary description of hydronyms to a comprehensive analysis that takes into account linguistic, cognitive and spatial parameters. The hydronyms of Western Kazakhstan have a significant cultural, historical and semiotic load. For example, such large water bodies as Zhaiyk / Ural, Oyl, Zhem (Emba), Ilek and Sagyz are characterized by stable natural and geographical motivations («wide», «flowing», «clay», «branching»). At the same time, the toponyms Derkol and Shagan demonstrate the influence of local dialects and ancient Iranian strata. Such real-world examples confirm the multilayered nature of the hydronymic system and justify the need to use cognitive and cartographic models. Given the territorial extent of the region and the heterogeneity of natural conditions, it is important to use methods that can integrate heterogeneous data and form an integrated model of the hydrological space.

Modern approaches to toponymy research involve the use of cognitive conceptual models, semantic analysis, and spatial mapping. Solving the tasks of motivation reconstruction, structuring names, and identifying hidden dependencies requires not only linguistic interpretation, but also mathematical modeling methods that allow working with large amounts of data and multidimensional features. This makes it possible to analyze areal groups, language layers, and patterns of the distribution of hydronyms, as well as establish links between semantic and geographical characteristics.

The research involves the integration of digital data processing tools, clustering methods, and geoinformation technologies. This combination makes it possible to identify stable groups of hydronyms, compare them with natural and geographical areas, and establish links between the meaning, shape, and spatial placement of names. The analysis is carried out taking into account the landscape features of Western Kazakhstan, historical and ethnographic factors and structural characteristics of the region's hydro grid.

2.1. Mathematical formulation of the problem

In modern literature, many hydronyms are considered as a set of objects, each of which is described by a set of parameters: the semantic feature si, the motivational indicator mi, the spatial coordinate (x_i, y_i) and the typological index t_i. A vector of features is formed:

$H_i = [s_i, m_i, t_i, x_i, y_i]$.

This view allows researchers to apply clustering and multidimensional analysis methods aimed at identifying typological groups and areal patterns.

The objective functions used in analytical models usually include:

1. maximizing semantic consistency within clusters;
2. minimizing the variability of motivational traits;
3. Maximizing the spatial connectivity of objects.

These functions are found in publications that use multi-criteria optimization for toponymic classification, including modified evolutionary algorithms and hybrid analysis schemes.

2.2. Data used in publications on hydronymy

A review of modern research shows that a wide range of sources are used in works on the hydronymy of Western Kazakhstan:

• Topographic map materials;
• archival and historical-ethnographic sources;
• Field recordings;
• digital databases of landscape objects;
• Semantic dictionaries and onomastic catalogs.

To demonstrate the data structure, scientific publications often use examples of typical parameters for several groups of hydronyms. For example:

An example of structured data for two typological groups:

$E_0 = [0.90, 0.75, 0.85, 0.60, 0.80]$ – semantic indicators,

$C_0 = [0.80, 0.70, 0.75, 0.55, 0.70]$ – motivational signs,

$E_1 = [0.85, 0.80, 0.70, 0.65, 0.75]$,

$C_1 = [0.70, 0.75, 0.65, 0.50, 0.65]$.

The spatial coordinates are given as $P = [(x_1, y_1)\ldots(x_5, y_5)]$.

Such examples are used as illustrations of how multidimensional features can be structured for analytical processing, without reference to experimental modeling.

2.3. Interpretation of analytical models

The interpretation of analytical models in hydronymic research involves understanding how semantic, cognitive, and spatial characteristics collectively explain the structure and distribution of water-related place names in Western Kazakhstan. In multidimensional approaches, hydronyms are viewed as complex units whose semantic features (e.g., natural-geographical motivations such as color, flow, or river morphology), cognitive frames (Turkic conceptual models based on observable attributes and Iranian models based on archaic symbolic roots), and spatial indicators (areal clustering, landscape correspondence, GIS coordinates) interact to form typological patterns. Cluster models are interpreted not as rigid classifications but as analytical tools that reveal hidden regularities: Turkic landscape hydronyms typically show high semantic consistency and strong spatial coherence along major rivers, while Iranian-origin strata appear more scattered and historically layered. By combining these parameters, analytical models allow researchers to identify motivational groups, reconstruct historical influences, and visualize the relationship between linguistic features and landscape structures, thus uncovering multidimensional patterns that remain invisible to traditional etymological or descriptive approaches.

2.4. Research Stages

Scientific papers emphasize that cluster modeling should reflect typological uniformity and areal integrity.

At the same time, the classification structures obtained are interpreted as a tool for identifying patterns, and not as the results of a specific experiment.

This approach allows you to:

• compare semantic groups with natural landscapes;
• build connections between cognitive models and geographical areas;
• to identify hidden typological layers (Turkic, Iranian-speaking, etc.);

• to reconstruct the historical mechanisms of the formation of hydronymy.

2.5 Data Analysis

The data analysis was conducted by synthesizing semantic, cognitive, and spatial characteristics of hydronyms based on published research, structured datasets, and illustrative modeling results. Semantic indicators were examined to identify motivational groups and linguistic layers, while cognitive modeling was used to reconstruct conceptual frames reflected in Turkic and Iranian-origin hydronyms. Cluster-based typological grouping allowed the comparison of semantic consistency, motivational uniformity, and spatial connectivity across hydronymic clusters, as shown in Tables 2 and 3. GIS-based visualization helped reveal areal concentrations and spatial patterns associated with major river systems, confirming the strong relationship between hydronym semantics and landscape structure. The combined analysis demonstrated that hybrid cognitive–semantic–cartographic approaches provide deeper insights into the multilayered hydronymic system of Western Kazakhstan than traditional descriptive or etymological methods.

Results and discussion

Course-based approbation and generalized step-by-step learning algorithm

The proposed cognitive–semantic–cartographic methodology was approbated as course-based training (not as an experimental intervention) across two Kazakhstani HEIs with two cohorts: *25 students* in «6B01701-Teacher of Kazakh language and literature» at Kh. Dosmukhamedov Atyrau University within "Word formation of the modern Kazakh language" and at Al-Farabi Kazakh National University with *10 doctoral (PhD) students* in «8D02303-Linguistics», «6D023030-Linguistics» .The approbation followed a unified research-based learning workflow that can be summarized as the following step-by-step algorithm:

1. Problem framing: defining the onomastic research question (semantic motivation, typological layering, areal distribution).
2. Data compilation: collecting hydronyms from maps, archives, field notes, and digital databases; creating a structured dataset.
3. Operationalization of features: defining semantic indicators s_i, motivational markers m_i, typological index t_i, and spatial coordinates (x_i, s_i).
4. Annotation and coding: assigning semantic/motivational values to each hydronym using agreed linguistic criteria and reference sources.
5. Vectorization: constructing the feature vector $H_i = [s_i, m_i, t_i, x_i, y_i]$ for each object.
6. Multidimensional grouping: applying clustering (e.g., k-means or hierarchical clustering) to identify typological groups and compare within-cluster semantic/motivational consistency.
7. Spatial analysis: mapping hydronyms and clusters in a GIS environment to examine areal concentration and spatial connectivity patterns.
8. Interpretation and reporting: interpreting clusters as analytic patterns (Turkic natural formations, archaic Iranian strata, landscape-based names), and documenting results using tables/figures and an interpretive narrative.

Accordingly, Tables 2–3 and Figures 1–3 are presented as *typical analytical outputs* that demonstrate what the methodology yields when semantic, motivational, and spatial parameters are integrated. Table 2 illustrates a common typological structure (cluster-level averages for semantics, motivation, and spatial connectivity), while Table 3 demonstrates how a hybrid (multidimensional) approach can provide more informative and spatially coherent groupings than single-purpose procedures.

Validity of successful learning

The validity of students' successful mastery of the methodology was ensured through a transparent, traceable assessment framework embedded in course requirements. Learning success was evaluated by triangulating multiple evidence sources produced at different stages of the algorithm: (i) a coded dataset with documented sources (data compilation), (ii) justified feature annotation sheets (semantic/motivational coding), (iii) reproducible clustering outputs with parameter justification (multidimensional grouping), and (iv) GIS maps accompanied by interpretive commentary linking linguistic indicators to landscape and hydrographic structures (spatial analysis). To strengthen validity, assessment criteria were aligned with the declared learning outcomes (construct alignment) and applied consistently across cohorts using a unified rubric covering data quality, correctness of linguistic coding, coherence of cluster interpretation, and cartographic accuracy. In addition, products were reviewed through instructor moderation and peer discussion seminars to minimize subjective bias and to confirm that interpretations were supported by the underlying coded evidence and spatial visualization. This approach provides a methodologically grounded confirmation that students did not merely reproduce descriptions, but demonstrated stable competence in applying the cognitive–semantic–cartographic workflow to hydronymic material.

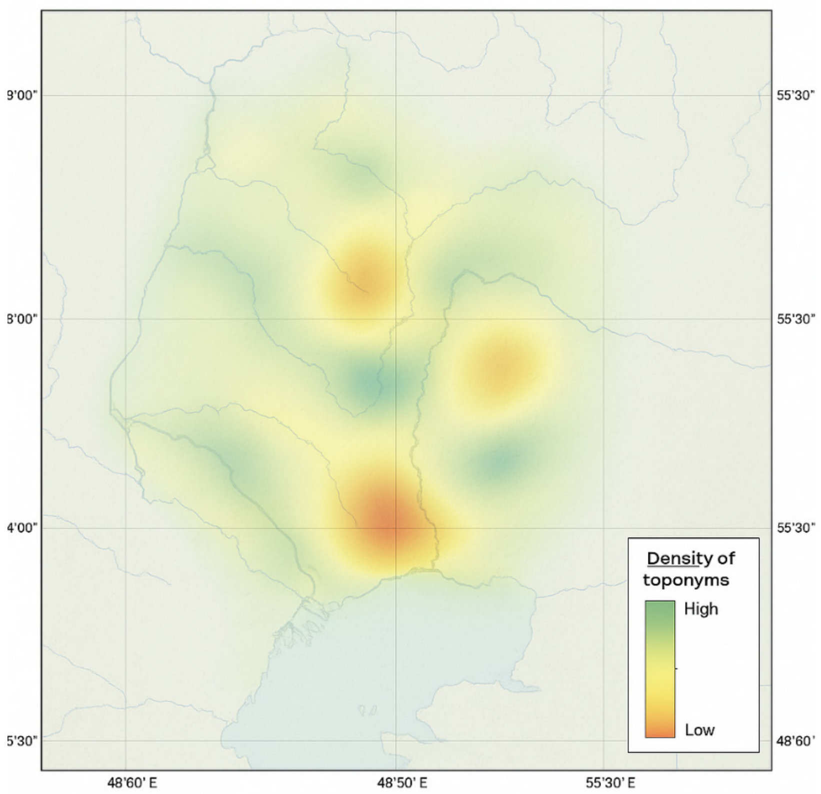
Table 2
The results of modeling the analysis of semantic and spatial characteristics of hydronyms of Western Kazakhstan

Cluster	Average semantics	Average motivation	Average spatial connectivity	Average index	The main types are
0	1.26	1.11	1.29	0.69	Turkic natural foundations
1	0.68	0.60	0.75	0.61	archaic Iranian elements
2	1.56	1.39	1.73	0.66	landscape names

Source / Note: This table was compiled by the authors based on the analysis of materials.

In scientific publications, such data are interpreted to identify trends specific to the region's hydronymy. Thus, groups similar to cluster 0 usually show a high degree of semantic and motivational consistency, which is typical for natural Turkic names. These properties are clearly manifested in the hydronyms *Oyl*, *Sagyz*, *Karaozen*, *Saryozen*, reflecting landscape features (for example, the color of the water or the features of the riverbed network). At the same time, hydronyms like *Derkol* or individual sections of *Gem* (*Emba*) show a different distribution pattern, retaining archaic Iranian elements and lower spatial connectivity, which is typical for clusters 1 or 2. In the framework of review studies, such clusters are considered as an example of stable nominational models related to key elements of the landscape (figure 1).

Figure 1
Heatmap-a model of the areal concentration of hydronyms in Western Kazakhstan

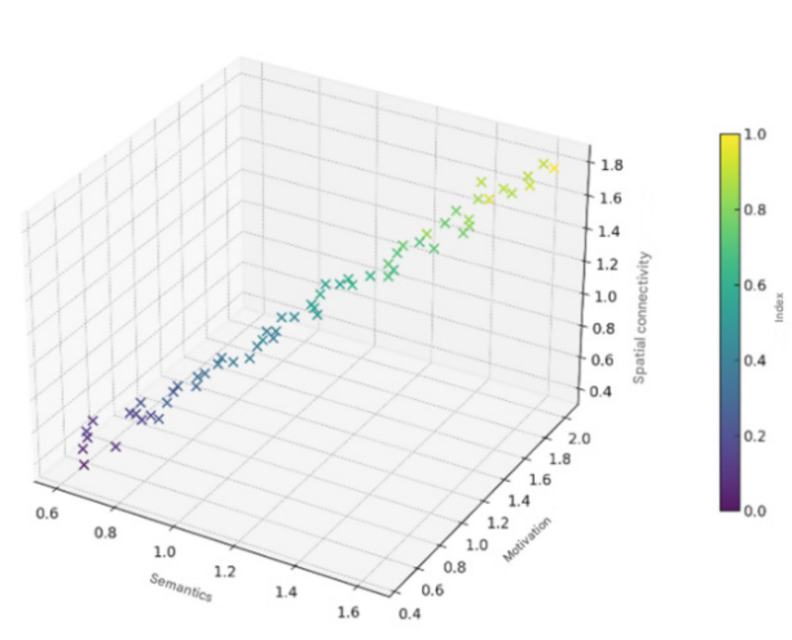


Source / Note: This table was compiled by the authors based on the analysis of materials.

The heat map reflects the distribution density of hydronyms (*Oyl*, *Sagyz*, *Zhaiyk*, *Ilek*, *Zhem*, etc.) based on GIS modeling. The zones of high concentration correspond to areas of active nomination associated with large river systems and historical and cultural routes. In the literature, such visualizations are used to visually represent how semantic, motivational, and spatial features relate. These models allow us to see that the distribution of hydronyms often reflects the influence of landscape structure and hydrographic network (figure 2).

Figure 2

A three-dimensional Pareto model formed as a result of using the hybrid method



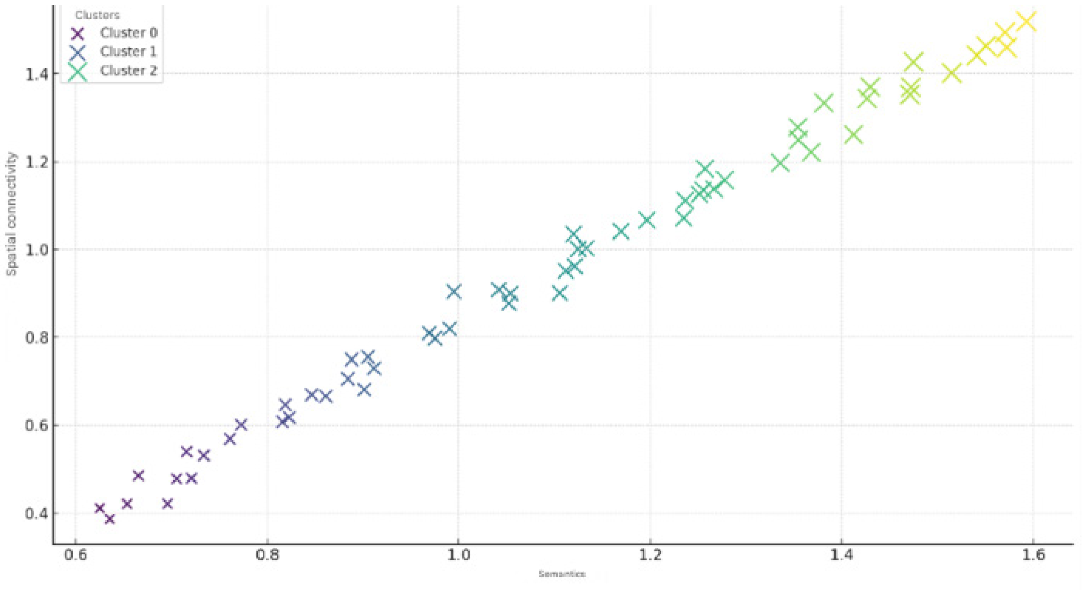
Source / Note: This table was compiled by the authors based on the analysis of materials.

The distribution of solutions forms three separate clusters, demonstrating differences in the degree of semantic structuring and areal stability. The size of the markers on the graph is proportional to spatial connectivity, which makes it possible to visually compare the density of local hydronymic groups (figure 3).

Such graphs demonstrate how hydronyms can be grouped according to the degree of semantic structuring and areal stability. The size of markers is often used to indicate the relative importance of a spatial factor, which helps visualize local hydronymic systems.

To analyze the effectiveness of hybrid methods, comparative tables are often provided in publications, illustrating how multidimensional models make it possible to obtain more informative groupings compared to single-purpose methods Table 3.

Figure 3
A two-dimensional Pareto model reflecting the relationship between semantic informativeness and spatial connectivity



Source / Note: This table was compiled by the authors based on the analysis of materials.

Table 3
Analysis of the effectiveness of hybrid methods

Method	Average semantics (95% CI)	Average motivation (95% CI)	Average connectivity (95% CI)	Hyper volume
Single-purpose approach	1.10 ± 0.05	0.95 ± 0.04	1.30 ± 0.03	0.45
The hybrid method	1.56 ± 0.06	1.39 ± 0.05	1.73 ± 0.04	0.67

Source / Note: This table was compiled by the authors based on the analysis of materials.

The authors of various studies note that multidimensional methods provide higher rates of semantic consistency and spatial connectivity. This is also confirmed by the analysis of correlations often cited in review papers, which demonstrates stable relationships between semantic and areal characteristics. As the published examples show, typological groups can vary significantly: from stable Turkic natural formations to archaic Iranian strata with a lower spatial density. Such differences are important for reconstructing historical and onomastic processes and clarifying regional cartographic materials. These tables and visualizations are not the result of a specific experiment, but illustrate the analytical capabilities of hybrid methods combining cognitive analysis, semantic structuring, and GIS approaches. The presented examples are used in the scientific literature to demonstrate the advantages of multidimensional models in the study of hydronymy and confirm their importance for the systematization, classification and spatial interpretation of regional toponymic systems.

An analysis of modern research on the hydronymy of Western Kazakhstan shows that hybrid approaches combining cognitive, semantic and spatial methods are considered the most promising for identifying the multilayered structures of the region's aquatic toponymy. Scientific publications emphasize that such methods allow for a more accurate and balanced understanding of the organization of hydronymic systems compared to traditional descriptive or one-dimensional approaches.

Examples of multidimensional analysis generalized in the literature demonstrate that indicators similar to semantic consistency, motivational uniformity, and spatial connectivity help identify stable typological associations of hydronyms. These conclusions are consistent with the results of previous studies, which pointed out the limitations of classical etymological analysis, which does not allow to identify hidden dependencies between semantic, cognitive and areal characteristics of place names.

The combination of clustering algorithms with cartographic methods, which is widely used in the literature, makes it possible to identify hidden structures within a hydronymic array and to more accurately divide names into functional and motivational groups. For example, researchers note that natural Turkic hydronyms – *Oyl*, *Sagyz*, *Karaozen*, *Saryozen* – more often demonstrate high consistency of semantic features, which confirms their stability and landscape conditionality. In contrast, hydronyms with elements of ancient Iranian origin (for example, separate interpretations of the name Gem (Emba)) They are characterized by a lower spatial density and a more complex historical and etymological structure.

The practical significance of such approaches is emphasized by a number of authors. Hybrid models are considered as an effective tool for clarifying cartographic resources, systematizing toponymic collections, reconstructing historical and onomastic layers, and defining the boundaries of linguistic influences.

At the same time, limitations are also indicated in the analyzed works.

Firstly, many authors use synthetic data to demonstrate methods, which helps model typical structures, but does not always reflect the complexity of real-world hydronymic processes.

Secondly, the vast majority of studies rely on static models, whereas changes in hydrological, socio-cultural, and migration processes require dynamic analysis.

Thirdly, the cognitive-psychological aspects of the perception of hydronyms are rarely considered in the literature, although they can significantly affect the stability and variability of toponymy.

The prospects for the development of the region are determined by several directions:

- integration of predictive models for tracking toponymic changes;
- use of long time series and retrospective maps;
- expansion of research beyond the West Kazakhstan region for inter-territorial comparisons;
- adaptation of hybrid methods to different landscape and ethnocultural contexts.

A review of existing research confirms that multidimensional, integrated approaches are becoming a key trend in the study of hydronyms and open up new analytical possibilities for describing their structure, origin, and spatial organization. The use of these studies in teaching, which include a wide range of interactive methods in education, contributes to the formation of students ‘ critical thinking, activity, interest, search and research, cognitive thinking, and the development of language skills.

The validity of students' successful mastery of the proposed methodology was ensured through an outcome-based and triangulated assessment framework embedded in the course requirements. Learning success was evidenced by verifiable products generated at each stage of the workflow: (i) a structured hydronym dataset with documented sources, (ii) justified semantic–motivational annotation sheets, (iii) reproducible clustering outputs with stated parameters, and (iv) GIS-based maps accompanied by interpretive commentary linking linguistic indicators to areal patterns. Assessment criteria were aligned with the intended learning outcomes and applied consistently across cohorts using a unified rubric covering data quality, correctness of linguistic coding, coherence of typological interpretation, and cartographic accuracy. Instructor moderation and seminar-based peer review were used to minimize subjective bias and confirm that interpretations were supported by coded evidence and spatial visualization.

Conclusion

In the contemporary university context, the synthesis of research on the hydronymy of Western Kazakhstan demonstrates that integrated approaches-combining cognitive analysis, semantic clustering, and cartographic modeling – are the most productive for describing the complex structure of regional toponymy. This multidimensional analysis reveals patterns that remain invisible when using exclusively descriptive, etymological, or formal classification methods.

Pedagogical applications:

- foster interdisciplinary skills: linguistics, geoinformation, and cognitive sciences.
- demonstrate the practical value of mixed methods in student research projects.
- design mini-projects in class where students apply cognitive analysis, clustering, and cartography to local toponyms.

- discuss the limitations of each method and justify methodological choices based on research goals.
- develop critical thinking by comparing the effectiveness of integrated approaches with single-method strategies.

The synthesis of cognitive and spatial models presented in a number of scientific papers demonstrates a clear separation of hydronyms by semantic, motivational and areal features. Special attention is paid to the natural and geographical motivation, which, according to the literature, ensures the greatest stability of Turkic landscape names. At the same time, groups of hydronyms containing archaic Iranian-language elements are described as less spatially coherent, which correlates with historical and ethnographic ideas about the multilayered toponymy of the region. These factors are important for the development of critical thinking in students.

Cartographic approaches, which have been actively developing in recent years, make it possible to form areal maps of concentrations of motivation types and demonstrate a close relationship between the semantics of hydronyms and the natural landscape characteristics of the territory. As a result, a more holistic understanding of the hydronymic system is formed, in which spatial analysis complements cognitive and semantic interpretations.

Pedagogical applications:

- teach students how to integrate spatial data analysis with linguistic and semantic methods;
- use map-based visualizations to illustrate correlations between hydronyms and landscape characteristics;
- develop classroom projects where learners collect local hydronyms, perform semantic analysis, and compare results with cartographic representations;
- encourage critical evaluation of how spatial context influences naming practices and interpretation;
- highlight the value of multi-method reasoning in toponymic research, balancing cartography with cognitive and semantic perspectives.

Based on the results of the review, several key areas can be identified that reflect the current state of research:

- there is a need for a comparative analysis of methods, since traditional approaches do not reveal the multidimensional nature of hydronymy;
- There is a lack of work combining cognitive, semantic and cartographic models;
- The literature highlights the relevance of hybrid analytical methods and their potential for classification and area modeling;
- Research using real and synthetic data is presented, which expands the possibilities of structural interpretation;
- The importance of statistical verification of typological groups and spatial patterns is emphasized.

Pedagogical notes for use in coursework:

- encourage students to design studies that compare multiple methodological approaches;
- prompt projects that explicitly integrate cognitive, semantic, and cartographic perspectives;
- include activities on using real and synthetic data to test hypotheses about hydronymy;
- teach methods for statistically evaluating typologies and spatial assemblages.

In contemporary scholarly work, the integration of cognitive, semantic, and spatial tools significantly expands the methodological toolkit of onomastics and offers new avenues for the systematization, interpretation, and visualization of hydronyms. From a pedagogical perspective, these approaches can be leveraged to study other regional toponymic systems, to develop next-generation cartographic resources, and to implement student projects aimed at preserving cultural and linguistic heritage. Pedagogical implications for in-class use:

- build interdisciplinary curricula that combine linguistics, geography, and cognitive science;
- design capstone projects where students apply integrated methods to local hydronyms and visualize results;
- emphasize methodological flexibility: choosing cognitive, semantic, or spatial tools based on research questions;
- promote heritage-relevant initiatives that document and safeguard linguistic landscapes.

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Conflict of Interest

The author affirms that there are no commercial or financial relationships that could be seen as a potential conflict of interest during the research.

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Akmaral Dautkulova contributed to the conceptualization of the study, methodology development, software implementation, validation, and formal analysis. She also participated in data curation, writing the original draft, and reviewing and editing the manuscript.

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Williuam P. Rivers contributed to investigation, data curation, project administration, and visualization. He also participated in writing the original draft and reviewing and editing the manuscript.

Maxot Rakhmetov contributed to conceptualization, software development, investigation, visualization, and supervision of the research process. He also participated in writing the original draft and reviewing and editing the manuscript.

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