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Development of a GIS digital framework for the Central Kazakhstan region based on cartographic materials and remote sensing data

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Abstract: The article is dedicated to the creation of a digital geoinformation framework for Central Kazakhstan based on the integration of various sources of spatial data. The aim of the study is to develop a structured GIS foundation capable of supporting analysis, ecological monitoring, and spatial modeling in a region with high natural resource potential. Methods included the integration of cartographic materials, remote sensing data, and digital elevation models, followed by georeferencing, vectorization, topology assessment, and spatial data analysis. Quantitative results showed that the hydrographic network of Central Kazakhstan includes 12,681 km of rivers and streams, 1,572 lakes with a total area of 11,354 km², as well as 63,028 km of roads and 8,288 km of railways. Accuracy assessment of digitized lake boundaries demonstrated high consistency between Landsat-9 and OSM (IoU = 0.86; Dice = 0.92). Morphometric derivatives such as slope, aspect, and hillshade were generated to delineate erosion-prone zones and assess land degradation risks. The practical significance of the research lies in the creation of an updated digital GIS framework that can be applied for spatial planning, environmental monitoring, infrastructure management, and scientific purposes. The developed system supports WebGIS platforms and can evolve into a regional digital twin using real-time data.

Keywords: GIS basis; digital map; cartographic materials; remote sensing data; Central Kazakhstan Region; spatial planning; digital framework; Central Kazakhstan GIS framework.

1. Introduction

In recent decades, the role of Geographic Information System (GIS) technologies has grown significantly, becoming a key tool in managing land resources, natural hazards, and environmental sustainability (Kurowska et al., 2020). The implementation of modern digital geoinformation technologies across various sectors of the national economy is aimed at fostering its intensification and optimizing the use of natural resource potential (Zhao et al., 2024). This, in turn, requires the availability of a high-quality, structured, and spatially referenced digital foundation.

GIS is a framework designed for the collection, storage, processing, analysis, management, and presentation of spatial or geographic data (Ananda et al., 2016). GIS data structures for analysis are defined as “themes of geospatial data identified as the basis upon which all other layers of data are structured and integrated for analysis and application” (Makanga et al., 2016).

In most high-income countries, large-scale maps and structured GIS data are readily available. However, in much of the world, such data remain largely inaccessible, and the available datasets are often stored in private databases held by non-governmental organizations and corporations (Tatem et al., 2007).

In Kazakhstan and Central Asia, several local studies have highlighted the challenges of pasture degradation, soil salinization, and vegetation change under climate variability and anthropogenic pressures. Vegetation phenology in Central Asia strongly responds to climatic gradients, emphasizing the need for systematic monitoring (Kariyeva & Van Leeuwen, 2011). More than 40% of Kazakhstan’s territory shows signs of significant land degradation, with pasturelands particularly vulnerable to overgrazing and desertification processes (Issanova et al., 2020). National reports of the Kazhydromet confirm that the region has experienced a steady warming trend and recurrent droughts, directly affecting vegetation productivity (Kazhydromet, 2020). These changes have contributed to the expansion of arid zones, with semi-arid lands progressively transitioning into more arid conditions across Central Kazakhstan (Bissenbayeva et al., 2025). These findings underline the necessity of developing a structured digital GIS framework that can integrate diverse datasets and provide a reliable basis for spatial planning and sustainable resource management in Central Kazakhstan.

The central region of Kazakhstan, with its vast territory and distinct natural and socio-economic characteristics, requires the development of a digital platform that can serve as a foundation for spatial analysis, monitoring, and modeling. For this reason, geoinformation systems have become ubiquitous. Data curation, map visualization, geocoding, and online deployment using GIS technologies represent user-generated content that is interactive, geolocated, and essential. However, Central Kazakhstan faces challenges such as a lack of regularly updated spatial data and limited public accessibility of geospatial information, which complicates planning and monitoring processes. Establishing a GIS foundation is a key stage in the creation of such a digital platform.

Study area. The study area – Central Kazakhstan consists of two administrative regions: Karagandy and Ulytau, with a total land area of 42.8 million hectares (Figure 1). The region includes a denudation plain known as the Kazakh Uplands, where steppe and dry steppe (semi-desert) soil and vegetation zones are clearly expressed, characterized by a semi-arid climate. This territory accounts for 37.4 million hectares of agricultural land, of which pastures – 35.2 million hectares or 94% of all agricultural land. 15.8% of the region's land (14.8 million hectares) is part of reserve lands, of which 87.2% are pastures (Pachikin et al., 2014).

The region plays an important role in the economic structure of Kazakhstan, with industries such as mining, agriculture, and energy production. There are about 13 thousand agricultural formations in the region. Livestock products account for 56.8% of the total gross production of the agricultural sector in the region under study. The livestock population in the region is growing both on farms and in private households. Due to the lack of pastureland, villagers are forced to keep their livestock practically in the yard, since pasture lands near settlements are not used for their intended purpose or are degrading. According to statistics from the Department of Agriculture of the Karaganda Region, as of January 1, 2022, the region contains about 800 thousand heads of cattle, over 1,381 thousand goats and sheep, and more than 537 thousand horses. Also, personal subsidiary farms contain about 321 thousand heads of cattle, about 474 thousand heads of small cattle, and more than 164 thousand horses (World Bank, 2021).

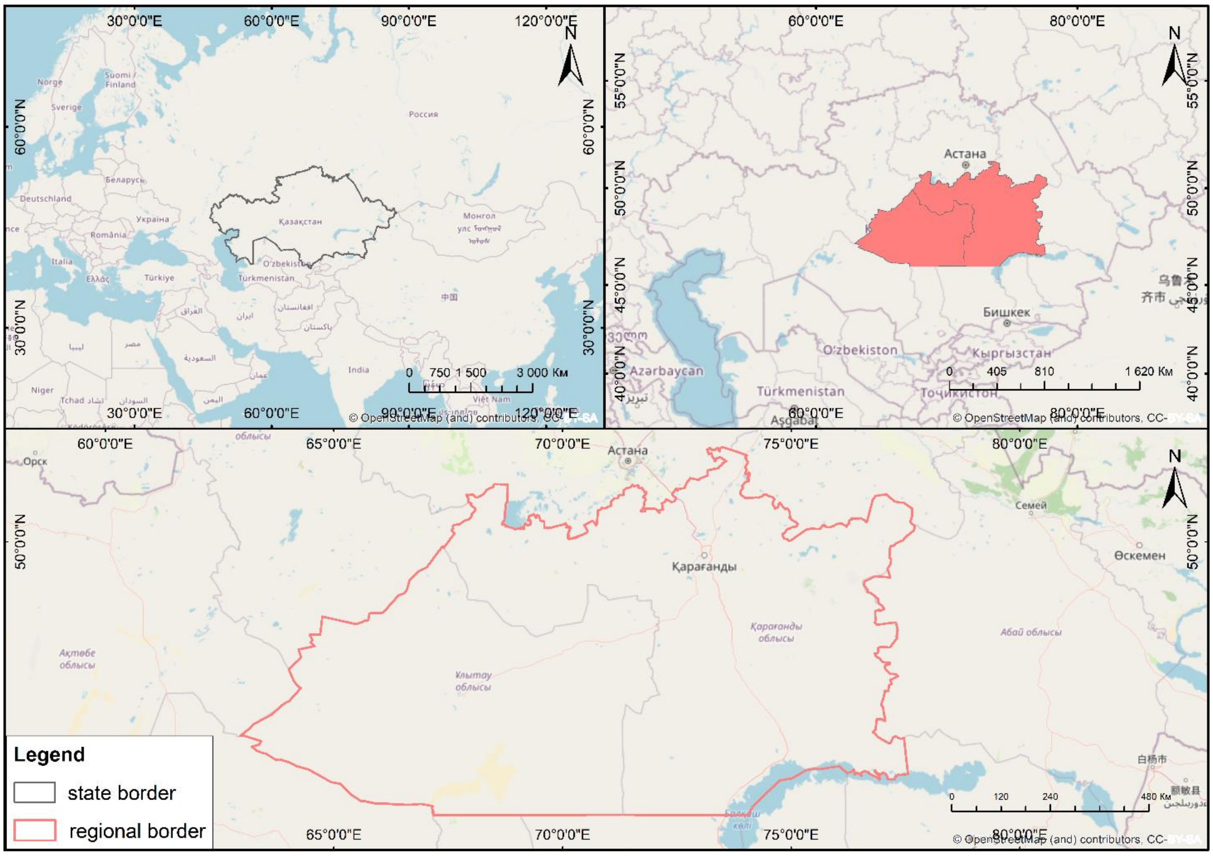

Figure 1. The object of the study (Source: compiled by author)

2. Materials and methods

2.1. Data Sources and Integration

The methodological workflow involved initial preprocessing, georeferencing, vectorization, attribute tagging, and conversion of raster datasets to analysis-ready layers.

The process of forming the digital GIS framework for Central Kazakhstan was based on a comprehensive approach that involved the integration of heterogeneous spatial data, including traditional cartographic materials, remote sensing (RS) data, and digital elevation models (Table 1), their structural unification, and subsequent analytical processing. This integration ensured spatial consistency across all thematic layers and provided a unified basis for further spatial analysis. Special attention was given to maintaining geodetic accuracy and semantic integrity when merging datasets from different sources and scales.

To implement the data integration and analysis procedures, several GIS tools were employed. ArcGIS Pro was utilized for georeferencing, digitization of cartographic sources, and raster-vector data management using tools such as Spatial Analyst and Raster Calculator (Esri, 2020). Google Earth Engine (GEE) was applied for cloud-based processing of satellite imagery, spectral indices calculation, and classification (Gorelick et al., 2017). These platforms ensured efficient handling of large datasets, spatial harmonization, and extraction of key landscape features essential for the regional GIS framework.

In the development of the digital GIS framework, an integrative geoinformation modeling method was applied, based on the combination of cartographic data, satellite imagery, and digital elevation models. This approach is recognized as effective for regional mapping of areas with diverse natural and geographical structures (Goodchild, 2007; Longley et al., 2015).

The key stages included correction of geometric and spectral characteristics, standardization of spatial resolution, and alignment of all data to a unified coordinate system (Burrough et al., 2015).

Scientific studies have shown that preliminary vectorization, mosaicking, and normalization of raster data significantly improve the quality of geoinformation frameworks for spatial analysis (Foody, 2002; Lillesand et al., 2015).

Table 1. Source data used for building the GIS framework of Central Kazakhstan

№	Data Source	Data Type	Spatial Resolution / Scale	Temporal Coverage	Source
1	Topographic Maps	Raster Maps	1:500 000 1:1 000 000	1987	https://maps.vlasenko.net
2	SRTM	Digital Elevation Model (DEM)	30 m	2000	NASA, USGS
3	Landsat 9	Satellite Imagery (Optical)	30 m (individual bands)	2024 (May - September)	USGS, EarthExplorer
4	OpenStreetMap (OSM)	Vector Data (roads, rivers, boundaries)	Vector layers	2025	https://www.openstreetmap.org

The methodological scheme applied in this study ensured the comprehensive preparation of data for subsequent modeling of natural and anthropogenic processes and is based on modern principles of geoinformation modeling, digital cartography, and remote sensing of the territory (Figure 2).

The applied methodological workflow was directly connected to regional challenges: Landsat imagery supported the detection of land cover transformations and land degradation processes; OSM data provided up-to-date information on settlement distribution and transportation accessibility, essential for estimating pasture load; and DEM derivatives such as slope and aspect facilitated the identification of erosion-prone areas.

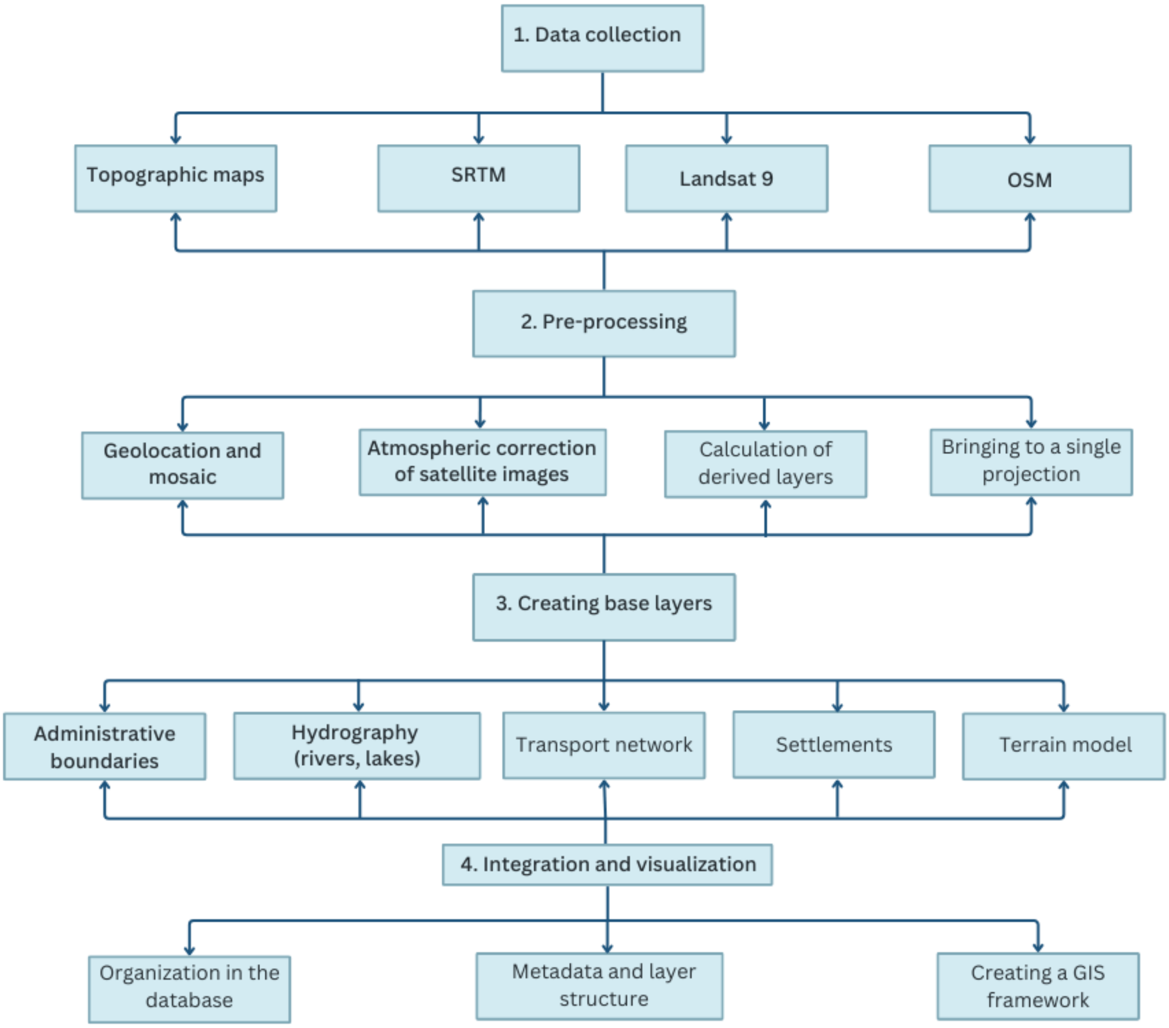

Figure 2. Methodological workflow of the GIS framework development (Source: compiled by author)

2.2. Data Preprocessing Workflow

Primary sources of spatial information included topographic maps at scales of 1:500,000 and 1:1,000,000, covering the main natural and geographical zones of Central Kazakhstan, including steppe, semi-desert, and desert areas of the Karaganda and Ulytau regions (Figure 3). These scales are optimal for regional mapping, providing a balance between detail and territorial coverage, as confirmed by several studies in the field of geoinformation modeling (Höhle, 2017).

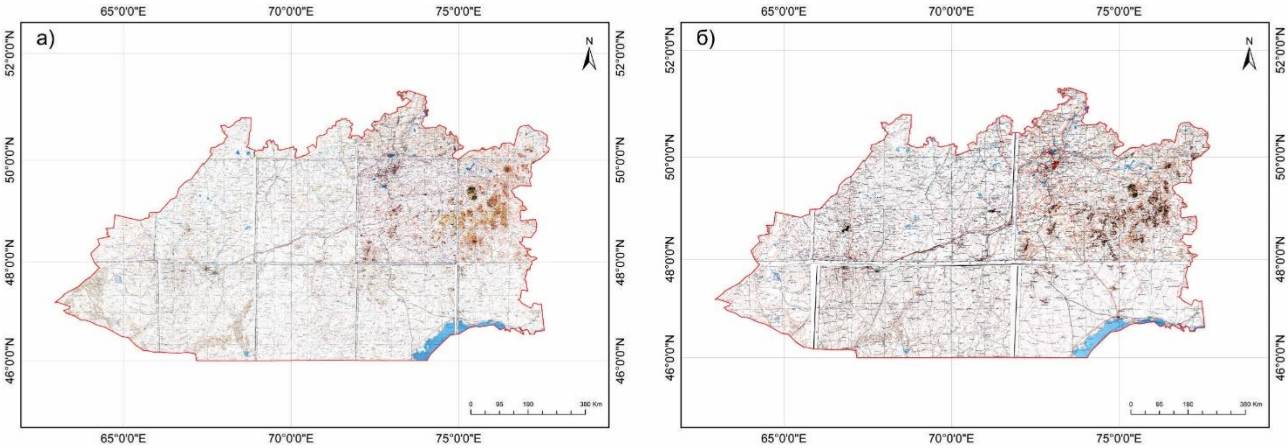

Figure 3. Topographic maps of Central Kazakhstan: a) 1:500 000; b) 1:1 000 000 (Source: compiled by author)

Topographic maps of this accuracy level maintain a high degree of reliability in the spatial positioning of natural and anthropogenic objects, especially in areas with low population density, where large-scale geospatial data are limited (Bocco et al., 2001). After geographic referencing, the maps were aligned to a unified coordinate system (WGS 84), ensuring compatibility with other spatial data sources. Based on these maps, vectorization of key components of the territorial structure was carried out, including the hydrological network, water body boundaries, settlements, and linear transport infrastructure objects. The resulting vector layers were structured and systematized for further use in GIS analytics and spatial modeling of the region's natural resource potential.

To improve the accuracy and completeness of the vectorized features, additional cross-validation with recent satellite imagery and ancillary datasets was performed. This step allowed the elimination of outdated objects and correction of positional inaccuracies, particularly in dynamic landscape zones. As a result, the final digital representation of the territory reflects both historical continuity and current geospatial realities.

To update and verify the spatial data used in creating the digital cartographic foundation of Central Kazakhstan, open geospatial data sources were utilized, meeting modern accuracy, accessibility, and spatial coverage requirements. Landsat-9 OLI/TIRS multispectral imagery was used as the primary remote sensing tool, providing an optimal combination of spatial and spectral resolution for analyzing land cover conditions and transformations (Roy et al., 2014; Wulder et al., 2019). These data enabled retrospective assessment of landscape changes over a defined observation period. An additional source of vector information was OpenStreetMap (OSM) cartographic data, widely used in applied and scientific research due to its high level of detail, regular updates, and open access (Haklay & Weber, 2008; Minghini et al., 2017). The use of OSM data allowed for refinement of the configuration of transport and settlement infrastructure, as well as individual land use objects (Figure 4).

The basis for constructing the Digital Elevation Model (DEM) of Central Kazakhstan was the SRTM (Shuttle Radar Topography Mission) model with a spatial resolution of 30 meters (Figure 5). The choice of this model is due to its global coverage, open access, stable accuracy, and wide application in scientific research. According to several studies, SRTM 30 m provides an optimal balance between spatial resolution and the volume of data processed when modeling terrain at the regional level (Jarvis et al., 2008; Reuter et al., 2007). For the Central Kazakhstan area, characterized by predominantly flat-hilly and weakly dissected terrain, the 30 m resolution is sufficient for generating key derivative layers such as slope, aspect, contours, and shaded relief images (Grohmann, 2015)

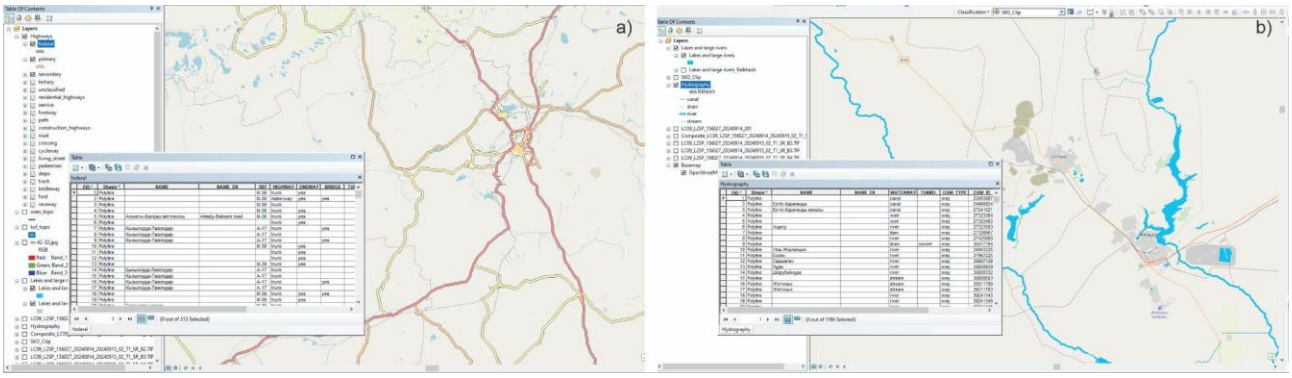

Figure 4. Vectorization of Spatial Objects from OpenStreetMap: a) road network; b) hydrological objects (Source: compiled by author)

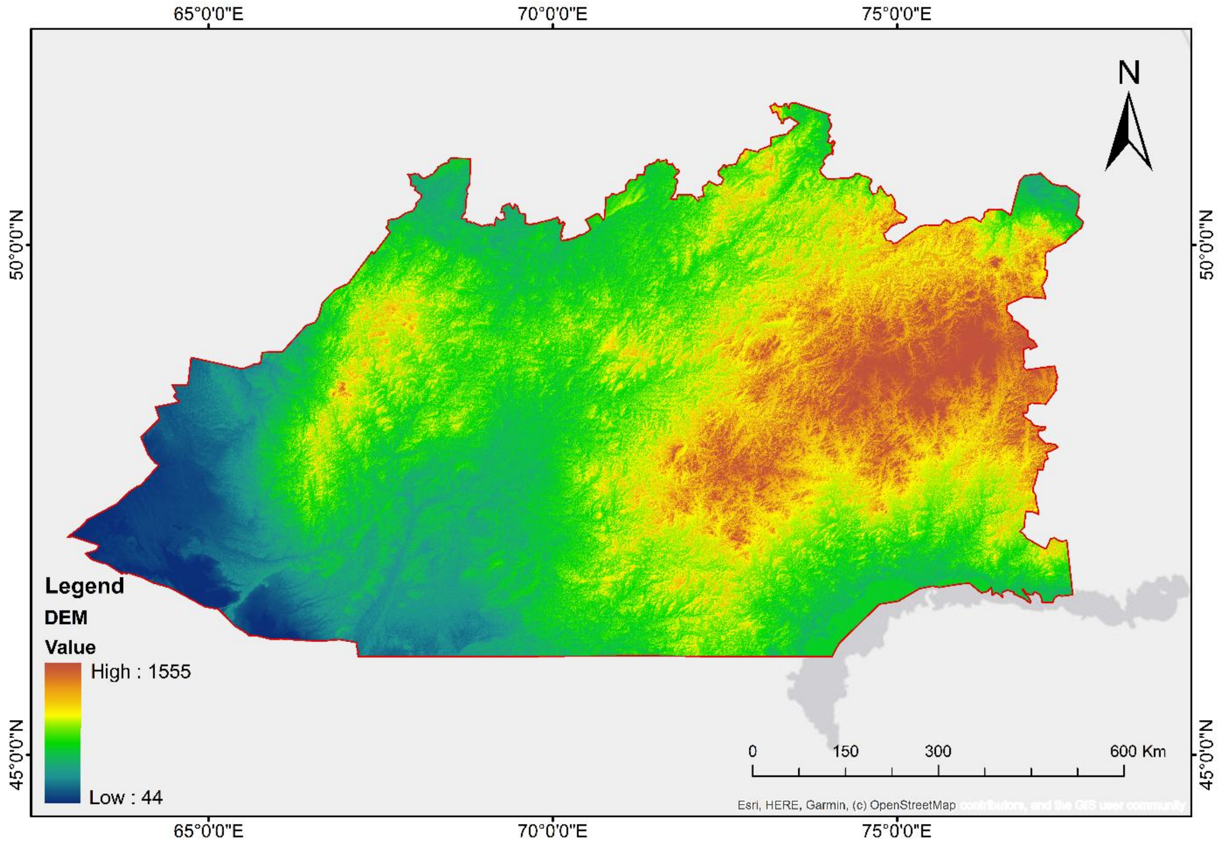

Figure 5. Digital Elevation Model of Central Kazakhstan Based on SRTM (Source: compiled by author)

Before conducting spatial analysis, all raster data were aligned to a unified geographic reference system (WGS 84) and clipped to the administrative boundaries of Central Kazakhstan, including the Karaganda and Ulytau regions.

Preprocessing of multispectral satellite imagery from Landsat 9 OLI/TIRS was carried out in the Google Earth Engine (GEE) environment, which enabled scalable, cloud-based processing of large geospatial datasets. This approach ensured not only time efficiency but also consistency in handling multi-temporal imagery, particularly for areas with frequent atmospheric interference. Next, the images underwent mosaicking based on median values for the growing season and normalization of reflectance (TOA Reflectance) to enhance comparability between dates and scenes (Figure 6).

To standardize the spatial resolution of all raster layers, the SRTM Digital Elevation Model was resampled to 30 meters using the bilinear interpolation method. This helped avoid abrupt transitions between pixels and ensured consistency with other raster data. After preprocessing, all raster data were exported in GeoTIFF format and imported into ArcMap, where unified raster layers were created. In ArcGIS, additional steps were carried out: renaming classes, calculating derivative parameters (such as slope, aspect, etc.), as well as visualizing and exporting thematic maps. The Raster Calculator, Extract by Mask, and Project Raster tools were used to prepare the data for subsequent spatial analysis and modeling.

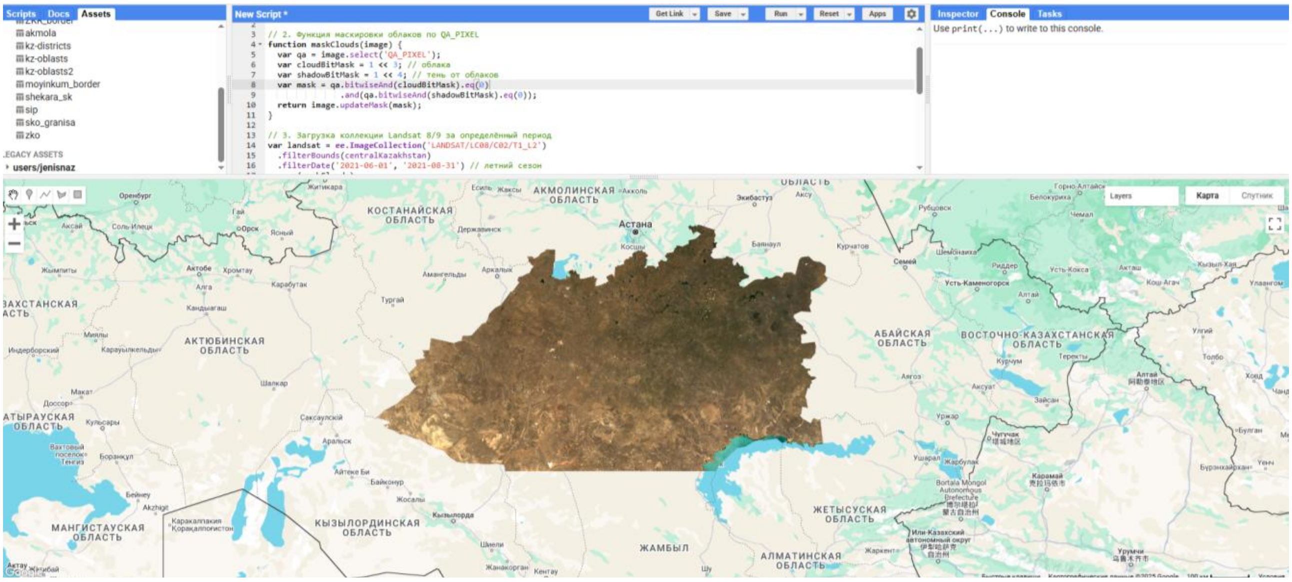

Figure 6. Preprocessing workflow of Landsat-9 OLI/TIRS imagery (Source: compiled by author)

Vectorization of topographic maps at scales of 1:500,000 and 1:1,000,000, covering the territory of Central Kazakhstan, involved extracting key elements of the spatial structure – riverbeds, lakes, seasonal watercourses, roads, railways, settlements, and more. The vectorization process was carried out in the ArcGIS environment using both manual and automated methods. The resulting vector layers underwent topological verification, categorization, and attribute structuring, ensuring their consistency and comparability with other spatial sources (Figure 7). The reliability of the spatial database was further evaluated through accuracy assessment procedures, with the corresponding results reported in the outcome section of the study.

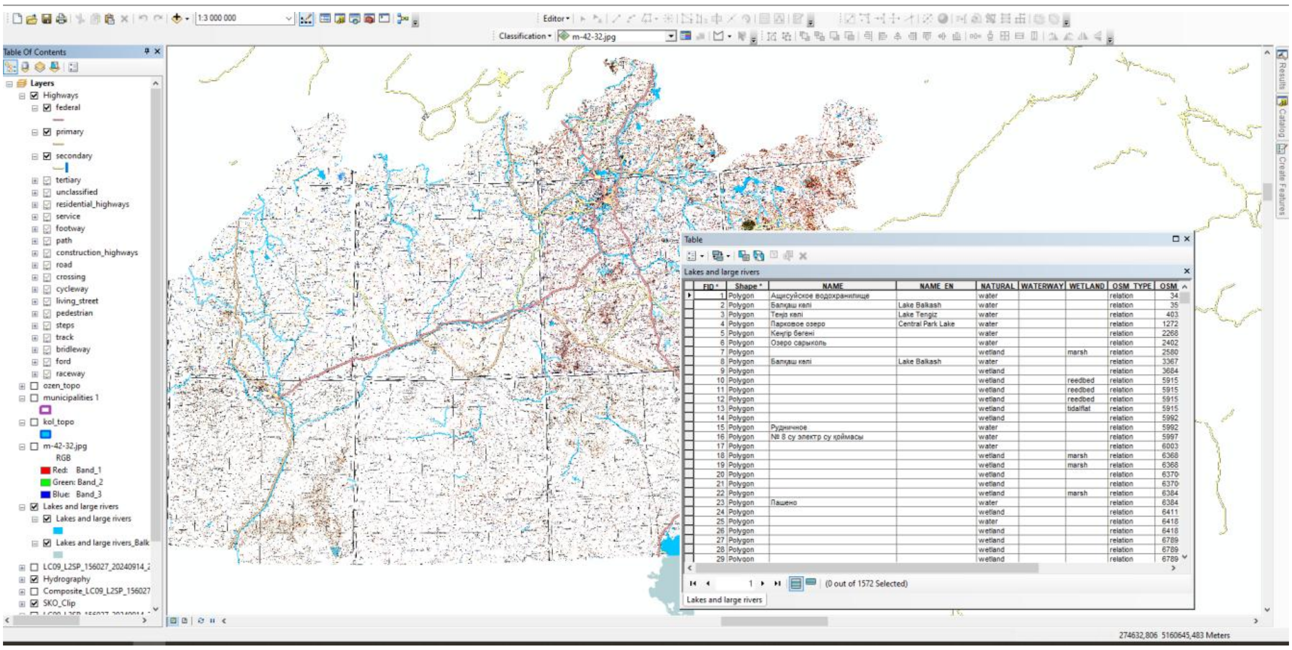

Figure 7. Vectorization and Attribute Structuring of Topographic Maps (Source: compiled by author)

3. Results

3.1. Data sources and integration

As a result of integrating heterogeneous spatial sources, a unified GIS foundation was formed for Central Kazakhstan, including raster, vector, and analytical layers suitable for subsequent thematic mapping and spatial modeling.

A structured spatial database was created based on the digitization of topographic maps at scales of 1:500,000 and 1:1,000,000. As a result of manual and semi-automated vectorization, layers for the hydrographic network, road infrastructure, mineral deposits, and settlements were obtained. The categorization conducted ensured consistency with contemporary sources (Figure 8). To enhance the reliability and spatial resolution of the database, vector layers were cross-validated with high-resolution satellite imagery and OpenStreetMap data. Attribute enrichment was carried out using both field survey records and statistical yearbooks, enabling thematic segmentation of infrastructure and land use. This integrated approach ensured high interpretability and scalability of the GIS database for regional-level analysis and decision support.

3.2. Comparative analysis of cartographic and open data

By overlaying vector layers created from topographic maps with modern open data sources (OSM, satellite imagery), spatial discrepancies were identified (Figure 9). The most significant differences were observed in the structure of temporary watercourses and small rivers; the configuration of lakes (including drying ones); the development of road infrastructure; and the growth or changes in the configuration of settlements. These differences reflect both natural landscape transformations over the past decades and anthropogenic pressures related to land use intensification and urbanization. In particular, the road network extracted from topographic sources significantly underrepresents recent expansions, especially around rural settlements and mining clusters. Comparative analysis enabled refinement of spatial boundaries and provided a basis for generating updated layers aligned with present-day land cover conditions.

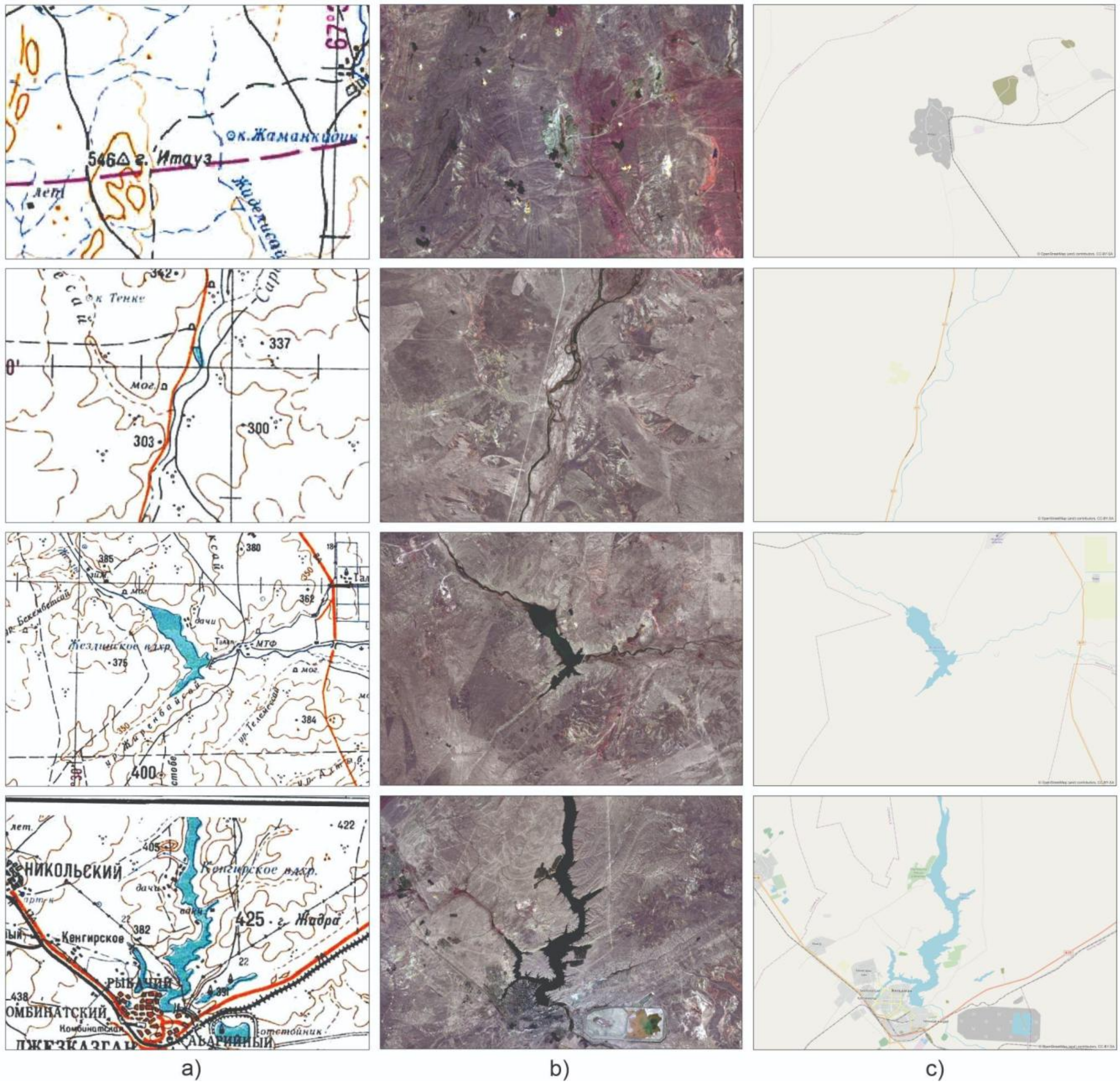

Figure 8. Comparative Vectorization Map from Different Sources: a) Topographic Map 1:500,000 (1987); b) Landsat 9 Image (14.09.2024); c) OpenStreetMap (2025) (Source: compiled by author)

3.3. Morphometric and relief analysis

Based on the SRTM 30 m Digital Elevation Model, derived layers were generated: slope, aspect, contour lines, and shaded relief (Figure 10). These layers were used to verify and refine the delineation of watersheds, assess the morphometric characteristics of the area, and construct the basic geomorphological framework of the region. The analysis of morphometric parameters allowed for the identification of key terrain features influencing hydrological processes and soil erosion risk. Slope and aspect data provided insights into solar radiation exposure and microclimatic variability affecting vegetation patterns. Additionally, shaded relief visualization enhanced the understanding of landform structures and facilitated the interpretation of geomorphological processes shaping the landscape.

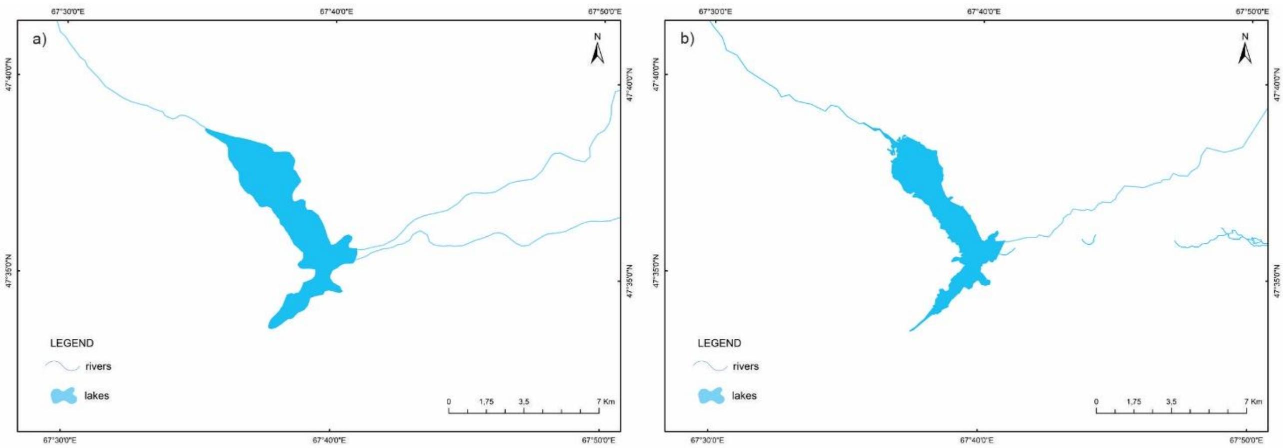

Figure 9. Comparison of hydrological features: a) topographic map; b) OSM data (Source: compiled by author)

Analysis of the slope map derived from the SRTM 30 m Digital Elevation Model revealed that slope values across Central Kazakhstan range from 0° to 70.91°. The majority of the area is characterized by slopes of up to 5°, indicating predominantly flat terrain. Areas with slopes greater than 15° are limited in extent and primarily associated with the Ulytau and Karkaraly mountain ranges. The resulting slope distribution enabled a preliminary morphometric zoning of the region and the identification of areas with increased erosion risk. For instance, zones with slopes exceeding 12° were marked as potential areas of accelerated water erosion, which can be considered in environmental planning and agricultural land use.

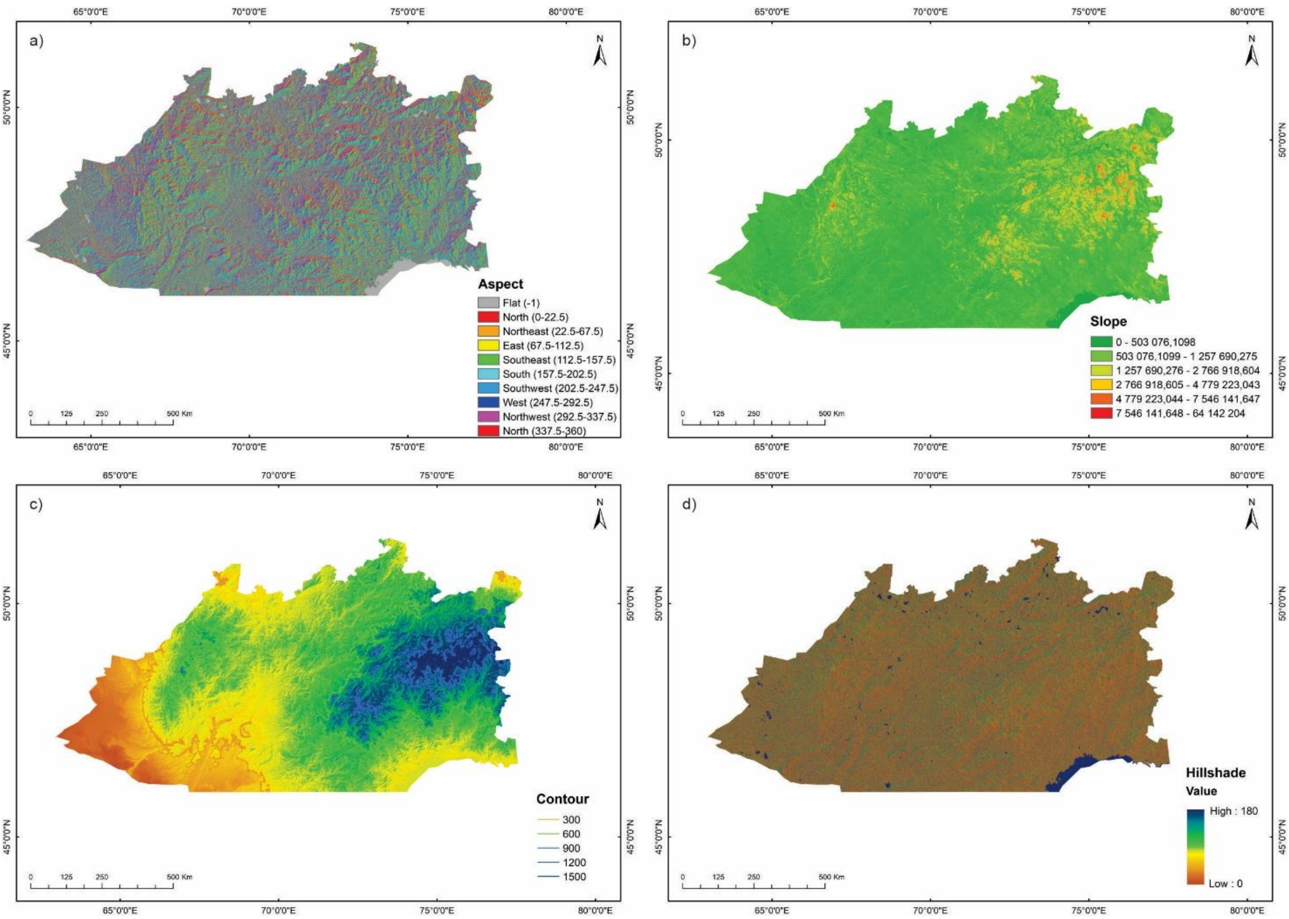

Figure 10. Composite map of relief-derived layers: a) slope; b) aspect; c) contours; d) hillshade (Source: compiled by author)

3.4. Mapping of settlements and infrastructure

As a result of processing and analyzing OpenStreetMap vector data (as of 2025), a current spatial model of the key territorial structure elements of Central Kazakhstan was constructed. The use of open geodata made it possible to obtain up-to-date quantitative and qualitative characteristics of features such as the hydrographic network, transportation infrastructure, and settlements (Figure 11).

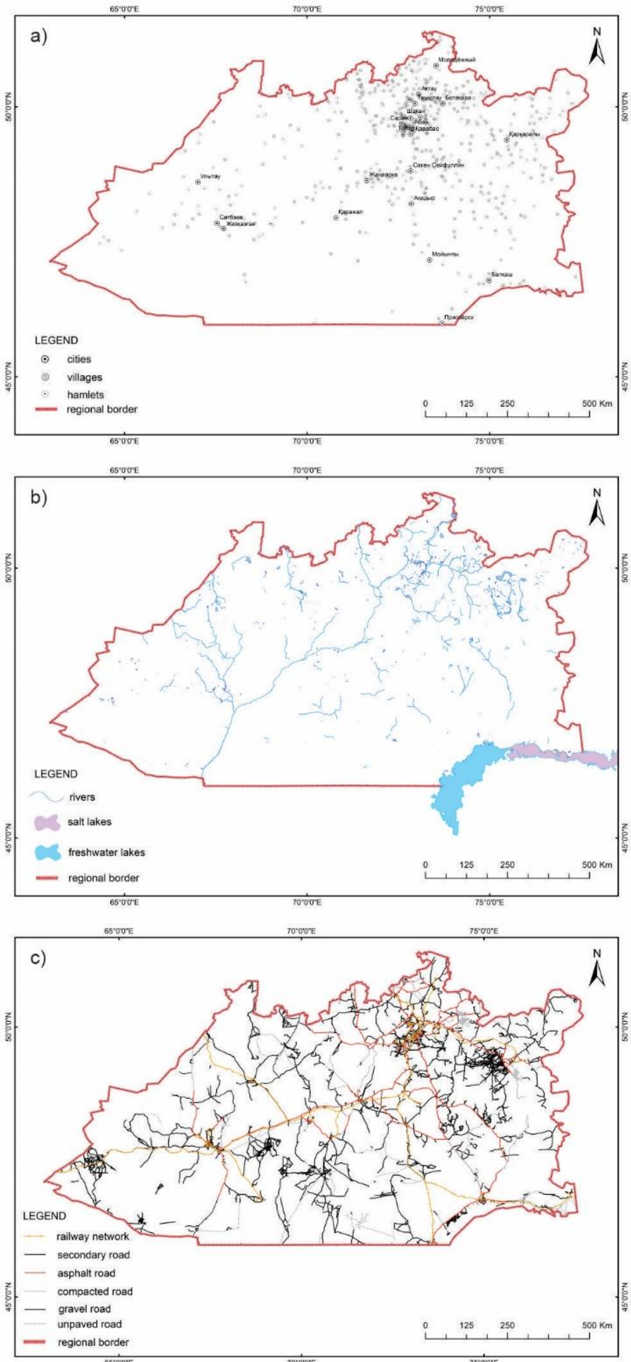

Figure 11. Results of feature digitization: a) settlements; b) hydrographic network; c) transportation network (Source: compiled by author)

Settlement distribution. Settlement density is highest along major transport corridors such as "Center-South" and "Astana-Almaty," and decreases significantly in peripheral semi-desert and desert zones. Remote settlements were identified, some located more than 50 km from the nearest paved road, indicating challenges for emergency and utility service access.

Transport connectivity. Comparative analysis of the road network revealed an increase in the length of tertiary and quaternary category roads by approximately 17% compared to 1987. The least connected areas are located southwest of Lake Balkhash and east of Zhezkazgan, with network gaps exceeding 100 km.

Remote areas. Combined analysis of relief and infrastructure layers made it possible to delineate zones with complex transport inaccessibility – areas that combine steep slopes (> 8°), absence of roads, and low settlement density.

The developed GIS foundation has demonstrated a wide range of applications in spatial planning and regional development:

1. Transportation planning. Slope and accessibility maps allow for the optimization of proposed transportation corridors, minimizing earthworks and avoiding ecologically sensitive areas.
2. Water resource management. The updated hydrographic network and DEM-derived layers (watersheds, slopes) provide a basis for runoff modeling and the planning of water control structures (e.g., check dams, small reservoirs).
3. Agro project design. The integrated GIS framework supports the zoning of land by erosion risk and pasture productivity, facilitating the rational allocation of agricultural lands and the implementation of soil conservation practices.

In addition, spatial analysis revealed that the most vulnerable areas to land degradation are concentrated in the southern and southeastern parts of Central Kazakhstan, particularly in semi-desert and desert zones with low vegetation cover and high grazing pressure. Infrastructure growth was most pronounced along major transport corridors and in mining regions, where settlement expansion and new road construction have intensified since the late 1980s. Conversely, peripheral areas located far from transport networks exhibit stagnation or decline, facing challenges in service provision and accessibility. These patterns highlight the uneven spatial development of the region and the need for differentiated management strategies.

3.5. Accuracy assessment of vectorized lake boundaries

To quantitatively evaluate the consistency of the digitized boundaries of Zhezdinskoye Lake derived from different sources (topographic map of 1987, Landsat-9 imagery of 2024, and OpenStreetMap of 2025), a comparative spatial analysis was conducted. The assessment included area calculations, intersection and union operations, and similarity indices (Intersection over Union – IoU, Dice coefficient, and relative area difference). These indicators are widely used in remote sensing and GIS studies to measure the geometric accuracy of vectorized features and ensure reproducibility of results (Guindon & Zhang, 2017).

Table 2 summarizes the results of the comparison. The highest agreement was observed between Landsat-9 and OSM boundaries (IoU = 0.86; Dice = 0.92), with only a 13.2% difference in area, indicating a strong consistency of these modern data sources. In contrast, the topographic map contour shows a significant overestimation of lake size (17.57 km² compared to 13.48 km² in OSM), resulting in a 30.3% area difference and a moderate similarity (IoU = 0.61; Dice = 0.76). A similar pattern is observed when comparing the topographic map and Landsat-9 (IoU = 0.62; Dice = 0.77; ΔArea = 15.1%).

Table 2. Accuracy assessment of Zhezdinskoye Lake boundaries from different sources

Comparison	Area_A (km²)	Area_B (km²)	Intersection (km²)	Union (km²)	IoU	Dice	ΔArea (%)
Topo vs OSM	17.57	13.48	11.77	19.36	0.61	0.76	30.3
Landsat vs OSM	15.26	13.48	13.25	15.49	0.86	0.92	13.2
Topo vs Landsat	17.57	15.26	12.58	20.25	0.62	0.77	15.1

These results confirm that historical topographic maps, while valuable for retrospective analyses, are less reliable for present-day assessments of hydrological systems. Modern datasets such as Landsat-9 and OSM provide more accurate delineations, reflecting both current hydrological conditions and ongoing anthropogenic influences. The proposed approach can be extended to other lakes and reservoirs of Central Kazakhstan, contributing to more accurate water resource assessments and supporting regional environmental monitoring.

3.6. Integrated map of Central Kazakhstan

As a final step, an integrated GIS map of Central Kazakhstan was developed (Figure 12), combining relief (hillshade), hydrology (rivers, lakes), infrastructure (roads, railways), and settlement layers. This synthesis map provides a holistic view of the region's territorial structure and serves as a cartographic basis for applied spatial planning, infrastructure design, and environmental monitoring.

In addition, the integrated map highlights spatial contrasts within the region, such as mountainous versus lowland zones, densely populated versus remote settlements, and saline versus freshwater lake systems. It allows for the identification of areas most vulnerable to land degradation and infrastructural isolation, thereby providing decision-makers with a visual tool for prioritizing development and conservation measures.

This final product not only reflects the current geospatial configuration of Central Kazakhstan but also serves as a reference model for comparative studies in other arid and semi-arid regions of Central Asia.

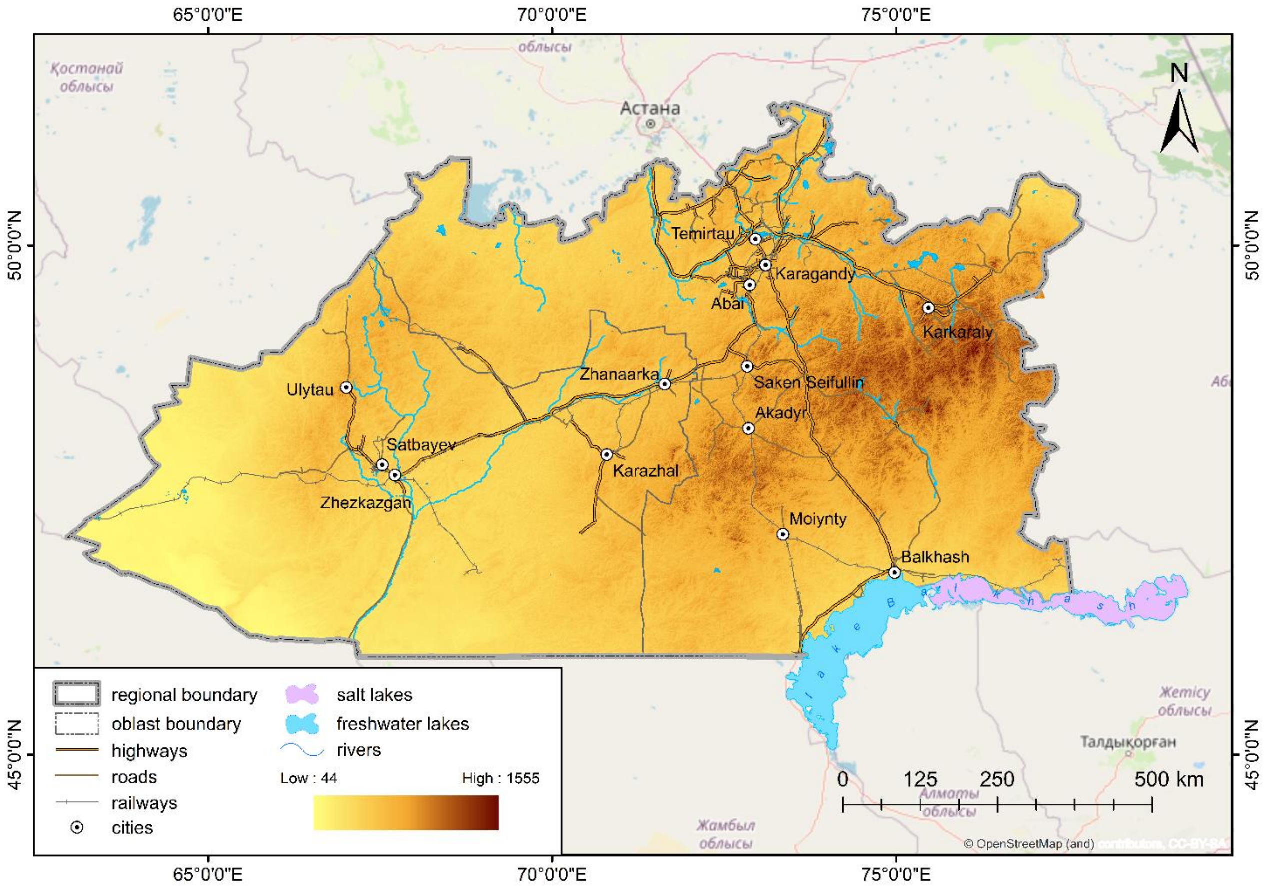

Figure 12. Integrated GIS map of Central Kazakhstan (Source: compiled by author)

4. Discussion

Based on the linear and polygonal hydrological features represented in OSM, a classification and quantitative assessment of water resources was carried out. The total length of rivers and watercourses amounted to 12,681 km. The total number of lakes, including unnamed ones, was 1,572, of which 107 have official names. The combined area of the lakes reached 11,354 km², indicating the significant impact of lake systems on regional water balances.

Analysis of transportation networks based on OSM vector data revealed that the total length of roads in Central Kazakhstan is 63,028 km, while the railway network extends for 8,288 km. The road network was classified by surface type: paved, compacted, gravel, and dirt roads. In addition, a functional classification was carried out, including railways, main roads, secondary roads, and rural roads.

According to point data of settlements from OSM, Central Kazakhstan contains 289 villages, 219 aul settlements, and 22 cities. These settlements were distributed by administrative-territorial units, considering their classification. The data obtained formed the basis for mapping population density and infrastructural accessibility across the region.

The resulting digital GIS framework of Central Kazakhstan can be effectively used for generating thematic maps in various fields (landscapes, infrastructure, ecology); producing visual and analytical reports and diagrams; developing web maps and 3D models for digital platforms, as well as for the creation of interactive web-based maps and 3D visualizations.

The integrated geospatial framework for Central Kazakhstan is designed as a modern, flexible platform ready to meet future challenges. It brings together harmonized and co-registered spatial layers, which serve as a direct input for advanced analytical tools. For instance, the updated hydrographic network (12,681 km) and lake systems (11,354 km²) provide a foundation for simulating water balance under drought scenarios, while infrastructure layers enable AI-driven accessibility analysis for rural settlements. These include AI-based applications such as land cover mapping, erosion risk assessment, drought forecasting, and crop yield modelling – using methods like Random Forest, convolutional neural networks (CNN), and long short-term memory (LSTM) architectures.

By connecting to near-real-time satellite data streams – such as Sentinel-1/2, MODIS, and VIIRS – the system can support the creation of a dynamic regional digital twin. This digital twin continuously updates key indicators, including vegetation stress, water reservoir levels, and wildfire activity. Unlike the earlier conceptual discussion, here the digital twin is directly linked to the newly obtained spatial layers, ensuring practical relevance for monitoring land degradation, pasture load, and hydrological dynamics in Central Kazakhstan.

The database design is cloud-native: fully compatible with ArcGIS Online, GeoServer, Cesium ION, and similar WebGIS platforms, enabling rapid publication of interactive 2D and 3D services for government agencies, researchers, and the public. In this respect, the framework parallels recent initiatives in the Mongolian Steppe (Munkhdulam et al., 2022), the Australian Rangelands (CSIRO, 2025), and the U.S. Great Plains (Miu et al., 2017). In the Kazakhstan context, the system complements national findings on climate-induced droughts and pasture degradation, but provides a novel digital foundation that integrates both retrospective maps and modern open data (Issanova et al., 2020).

Despite the results achieved, certain limitations remain, such as the heterogeneity and fragmentation of source data; challenges in automating the processing of unstructured sources; and the need to adapt to modern IT trends – including the use of cloud-based GIS services, artificial intelligence, and neural networks for image analysis.

5. Conclusion

This study introduces a novel geospatial framework for Central Kazakhstan through the integration of historical topographic sources, contemporary satellite imagery, and open-source geospatial data. For the first time, a comprehensive and unified digital GIS model of Central Kazakhstan has been developed, combining heterogeneous spatial layers into a standardized, interoperable environment.

The methodological workflow encompassed the full geospatial data cycle – collection, preprocessing, classification, vectorization, and verification – resulting in a spatial model that reflects the region’s natural and human-made landscape. Core outputs include:

- Generation of morphometric derivatives (slope, aspect, contours, hillshade) that enabled zoning of erosion-prone territories;

- Mapping of hydrological networks (12,681 km of rivers and streams; 1,572 lakes with a combined area of 11,354 km^2), transportation infrastructure (71,316 km of roads, classified by surface type), and populated areas (530 settlements by administrative units);

- Development of thematic layers on population density and infrastructural accessibility, which were not previously available for Central Kazakhstan in a unified digital format.

The novelty of this research lies in the development of an integrated, bilingual (Kazakh/English) digital environment tailored for arid and semi-arid regions with scarce geospatial infrastructure. It represents the first digital GIS foundation of its kind for Central Kazakhstan, ensuring both historical continuity and modern accuracy.

The system is designed to evolve into a dynamic digital twin of the region. It can integrate real-time data from satellites – such as Sentinel-1, Sentinel-2, and MODIS – as well as unmanned aerial vehicles (UAVs), to monitor vegetation conditions, water dynamics, and human-induced changes. Practical applications include support for the Ministry of Agriculture of Kazakhstan in assessing pasture degradation and optimizing land use, for Kazhydromet in hydrological and climate monitoring, and for regional administrations in transportation planning and rural development.

Future development of this GIS framework may include integration with AI-based classification tools, real-time sensor data, and web-GIS interfaces for public access and stakeholder engagement. Further work should focus on automating feature extraction, expanding temporal analysis, and developing user-oriented GIS applications for planning and management.

6. Supplementary Materials: No supplementary material.

7. Author Contributions

Conceptualization - Sh.K., N.Zh.; methodology - O.T.; software - Zh.T.; validation - Sh.K., N.Zh., K.Z.; formal analysis - K.Z.; investigation - O.T.; resources - A.A.; data curation - D.T.; writing-original draft preparation - N.Zh.; writing-review and editing - O.T.; visualization - Zh.T.; supervision - Sh.K.; project administration - O.T.; funding acquisition - O.T. All authors have read and agreed to the published version of the manuscript.

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Орталық Қазақстан өңірі үшін картографиялық материалдар мен қашықтықтан зондтау деректері негізінде сандық ГАЖ-негізін әзірлеу

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Андатпа. Мақала Орталық Қазақстан үшін әртүрлі кеңістіктік дереккөздерді біріктіру негізінде цифрлық геоақпараттық негіз құруға арналған. Зерттеудің мақсаты – талдау, экологиялық мониторинг және кеңістіктік модельдеуді қолдай алатын құрылымданған ГАЖ негізін әзірлеу. Әдістерге картографиялық материалдарды, қашықтықтан зондтау деректерін және сандық биіктік модельдерін интеграциялау, кейін оларды геожүйелеу, векторлау, топологияны бағалау және кеңістіктік деректерді талдау кіреді. Сандық нәтижелерге сәйкес, Орталық Қазақстанның гидрографиялық желісі 12 681 км өзендер мен салалары, жалпы ауданы 11 354 км² болатын 1 572 көлді, сондай-ақ ұзындығы 63 028 км автомобиль жолдары мен 8 288 км темір жолдарын қамтиды. Көлдердің векторланған шекараларының дәлдігін бағалау Landsat-9 пен OSM деректерінің жоғары сәйкестігін көрсетті (IoU = 0.86; Dice = 0.92). Бедердің еңістік, экспозиция және рельеф көлеңкелеуі сияқты морфометриялық туындылары эрозияға бейім аумақтарды айқындау және жердің тозу қаупін бағалау үшін пайдаланылды. Зерттеудің практикалық маңыздылығы аумақтық жоспарлау, қоршаған ортаны бақылау, инфрақұрылымды басқару және ғылыми мақсаттар үшін пайдалануға болатын жаңартылған цифрлық ГАЖ жүйесін құру болып табылады. Әзірленген жүйе WebGIS платформаларын қолдайды және нақты уақыт режимінде деректерді пайдаланатын аймақтық цифрлық аналогқа айналуы мүмкін.

Түйін сөздер: ГАЖ негізі; сандық карта; картографиялық материалдар; қашықтықтан зондтау деректері; Орталық Қазақстан; кеңістіктік жоспарлау; цифрлық негіз; Орталық Қазақстан ГАЖ негізі.

Разработка цифровой ГИС-основы для региона Центрального Казахстана на основе картографических материалов и данных дистанционного зондирования

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Аннотация: Статья посвящена созданию цифровой геоинформационной основы для Центрального Казахстана на базе интеграции различных источников пространственных данных. Цель исследования – разработать структурированную ГИС-основу, способную поддерживать анализ, экологический мониторинг и пространственное моделирование в регионе с высоким природно-ресурсным потенциалом. Методы включали интеграцию картографических материалов, данных дистанционного зондирования и цифровых моделей рельефа, с последующей геопривязкой, векторизацией, оценкой топологии и анализом пространственных данных. Количественные результаты показали, что гидрографическая сеть Центрального Казахстана включает 12 681 км рек и ручьёв, 1 572 озера общей площадью 11 354 км², а также 63 028 км автомобильных дорог и 8 288 км железных дорог. Оценка точности векторизованных границ озёр продемонстрировала высокую согласованность данных Landsat-9 и OSM (IoU = 0.86; Dice = 0.92). Для определения зон, подверженных эрозии, и оценки рисков деградации земель были созданы морфометрические показатели, такие, как наклон, вид и оттенок холмов. Практическая значимость исследования заключается в создании обновленной цифровой ГИС-системы, которая может быть использована для территориального планирования, мониторинга окружающей среды, управления инфраструктурой и научных целей. Разработанная система поддерживает платформы WebGIS и может стать региональным цифровым аналогом, использующим данные в режиме реального времени.

Ключевые слова: ГИС-основа; цифровая карта; картографические материалы; данные дистанционного зондирования; Центральный Казахстан; пространственное планирование; цифровая основа; ГИС-основа Центрального Казахстана.