
June 2026
GEORGIAN
GEOGRAPHICAL
JOURNAL
Vol. 6 No. 1 (2026)
UNIVERSITAS TPHILISIENSIS
1918
GEOGRAPHICAL SOCIETY OF GEORGIA
GSG
ISSN 2667-9701
9 772667 970002
Credit: Nana Kvirkvelia

Subscriptions and advertising

Georgian Geographical Journal (GGJ) is peer-reviewed and Open Access journal. It aims to strengthen the academic exchange of results in all fields of Natural and Human Geography research between Georgia, the Caucasus region, and other neighbouring countries. Journal reflects the latest geographical research achievements, related to the spatial patterns at the Earth's surface, as well as global issues and regional comparisons.

GGJ recognizes and follows worldwide publishing norms and best practices. It adheres to the internationally accepted values and practices of the Publishing Ethics Committee's (COPE) basic principles.

GGJ publishes two issues a year, in June and December.

Please visit https://journals.4science.ge/index.php/GGJ/indexed to view a full list of databases in which this journal is indexed

Published in Georgia

Table of Contents

Georgian Geographical Journal

6(1) • June 2026

Special Issue: Geographical Dimensions of Environmental Transformation and Sustainable Development in the Caucasus

Guest Editor: Dr. Zaur Imrani

The Caucasus stands at the crossroads of environmental transformation, economic modernization, and sustainability transitions. Guiding this special issue is Dr. Zaur Imrani, Director of the Institute of Geography of Azerbaijan, whose scientific career has been devoted to exploring the geographical dimensions of regional development, environmental change, tourism systems, and spatial planning. Combining expertise in geography, geoinformation technologies, and sustainable development, he has led major research initiatives and published widely in international journals. His work bridges science, policy, and regional cooperation, making him exceptionally positioned to curate a collection that addresses the pressing environmental and developmental challenges facing the Caucasus in the twenty-first century.

Guest Editor
Georgian Geographical Journal
Zaur Imrani

The Anniversary Celebrates the People of the Society: Emil Racoviță and Marcian Bleahu

Romeo-Alexandru Perlik[1]
[1] The Romanian Federation of Speleology
corresponding author: romeoperlik@yahoo.com

Georgian Geographical Journal, 2026, 6(1) 5-13

DOI:
https://journals.4science.ge/index.php/GGJ

Citation: Romeo-Alexandru, P. The Anniversary Celebrates the People of the Society: Emil Racoviță and Marcian Bleahu. *Georgian Geographical Journal* 2026, 6(1), 5-13. https://doi.org/10.52340/ggj.2026.06.01.02

Abstract

This paper highlights the monumental contributions of Emil Racoviță and Marcian Bleahu to Romanian speleology, marking milestones such as the anniversary of the Romanian Geographical Society. It traces the development of biospeleology and physical speleology from early campaigns in the Apuseni Mountains to the foundation of the world's first speleological institute. Additionally, the text reviews recent advancements by the Romanian Federation of Speleology, including the 2020 Karst Map, LiDAR scanning, and 3D cave visualisation projects. Exceptional natural landmarks are discussed, including the record depth of Grind Shaft and the length of Wind Cave, the unique ecosystem of Movile Cave, the unique beauty of Piatra Altarului Cave, and the oldest evidence of prehistoric art in Coliboaia Cave. Over 10,000 new caves have been discovered since 1976, with the establishment of the Central Commission for Sport Speleology (CCSS), explored, documented, and registered in the National Cadastre of Caves in Romania, maintained by the "Emil Racoviță" Institute of Speleology (ISER), leading to a current total of over 12,600 caves inventoried by ISER. Through these examples, the work demonstrates the interdisciplinary character of modern exploration. In conclusion, this highlights the importance of protecting and preserving underground heritage.

Keywords: speleology, Emil Racoviță, Marcian Bleahu, karst morphology, cave exploration, underground heritage

Introduction

Having Emil Racoviță (15 November 1868, Iași – 19 November 1947, Cluj) and Marcian Bleahu (14 March 1924, Brașov – 30 July 2019, Bucharest) as founding figures and mentors, and on the occasion of the 150th Anniversary of the Romanian Geographical Society (Romanian Geographical Society, n.d.), the Romanian Federation of Speleology (RFS) (Romanian Federation of Speleology, n.d.), which recently celebrated its 50th anniversary, extends its gratitude, congratulations, and best wishes for future achievements on behalf of Romania's organized and nationally recognized cave exploration community.

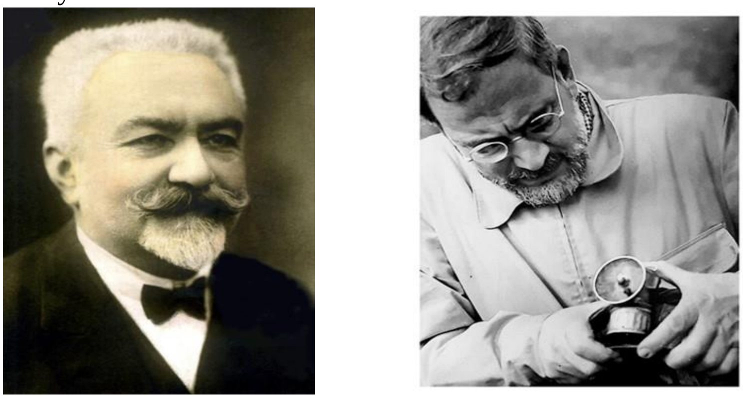


Figure 1. Emil Racoviță (15 November 1868, Iași –19 November 1947, Cluj) and Marcian Bleahu (14 March 1924, Brașov –30 July 2019, Bucharest)

Emil Racoviță (Fig. 1, left) was a distinguished scientist, explorer, speleologist, and biologist. He is internationally acknowledged as the founder of biospeleology, the scientific discipline devoted to the study of subterranean fauna inhabiting caves, groundwater aquifers, and other underground environments (Tabacaru & Danielopol, 2020).

Racoviță was among the foremost promoters of natural sciences in Romania and became the first Romanian scientist to participate in a scientific expedition to Antarctica, as a member of the renowned Belgian Antarctic Expedition (1897–1899) (Fig. 2).

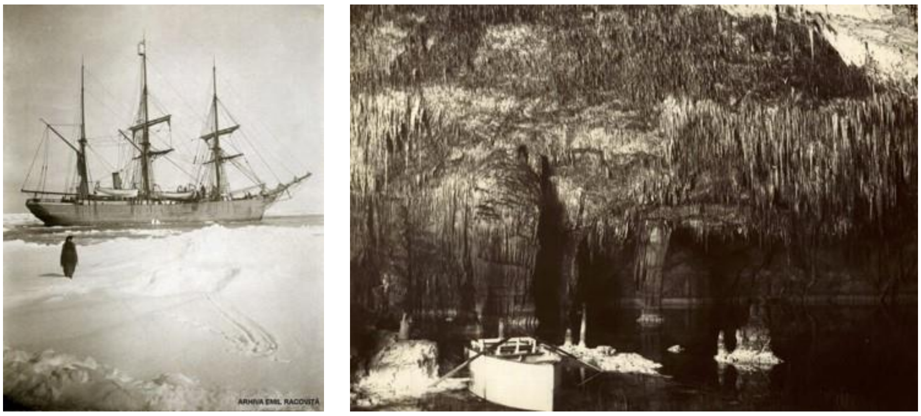


Figure 2. Belgian Antarctic Expedition (left); Cueva del Drach (right)

A bust of Emil Racoviță stands on the island of Mallorca, in the western Mediterranean. During a visit to Cueva del Drach in 1904 (Fig. 2), he discovered a small crustacean species adapted to the unique ecological conditions of subterranean habitats, a finding that contributed significantly to the emergence of biospeleological research.

Figure 3. The first speleology institute in the world

Marcian Bleahu (14 March 1924, Brașov – 30 July 2019, Bucharest) was a geographer, geologist, speleologist (Fig. 2 (right)), mountaineer, explorer, author, university professor, politician, Minister of the Environment, and Senator of Romania (Onac, 2019).

He is widely regarded as one of the founders of physical speleology, particularly through his contributions to karst geomorphology and speleogenesis, while also serving as a mentor to generations of Romanian cave explorers.

The Apuseni Mountains (Fig. 4-left) provided a scientific link between these two outstanding scholars. Where Racoviță initiated his biospeleological campaigns during the summer of 1921, studying among other sites the Scărișoara Ice Cave (Fig. 4-right), home to one of the world’s largest underground ice bodies and an important paleoclimatic archive exceeding 120,000 cubic metres of ice, Marcian Bleahu later continued this scientific tradition.

Together with researchers from the “Emil Racoviță” Institute of Speleology (ISER), Bleahu participated in numerous expeditions that led to the discovery, exploration, and surveying of several remarkable cave systems, including Cetățile Ponorului – Lost World System (Fig. 5-left), the largest karst system in Romania, featuring a doline approximately 1 km in length and 300 m deep, whose wall contains a cave entrance exceeding 70 m in height. He also contributed to the exploration of Vârtop Ice Cave (Fig. 5-right), renowned for the discovery of prehistoric human footprints dated to approximately 62,000 years ago, among many other significant karst phenomena (Onac et al., 2005).

Figure 4. Apuseni Mountains (left), Scărișoara Ice Cave (right)

His collaboration with ISER researchers and participation in extensive speleological expeditions resulted in the publication of numerous monographs and influential works dedicated to caves, karst landscapes, and subterranean environments.

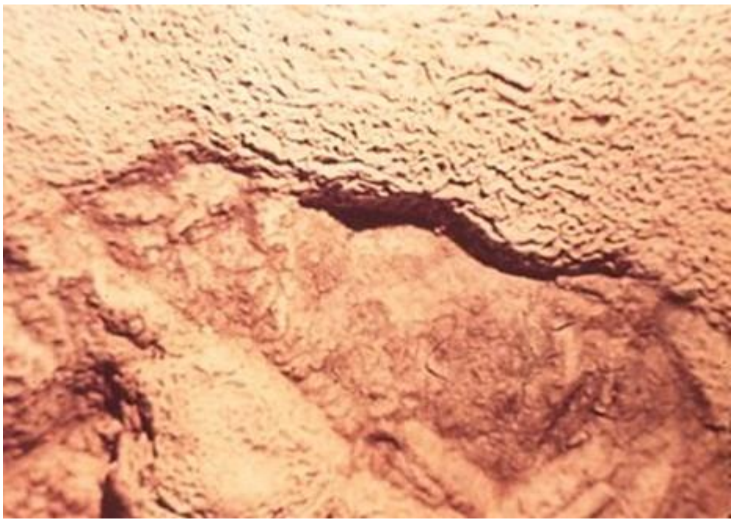


Figure 5. Cetățile Ponorului (left), Vârtop Ice Cave, prehistoric human footprints (right)

Marcian Bleahu graduated from the Faculty of Sciences in 1949, specialising in Natural Sciences and Geography. In 1974, he earned a PhD in Geography from the University of Cluj with a dissertation titled "Karst Morphology – Geological and Geographical Controls of Karstification Processes" (Fig. 6).

Bleahu authored or co-authored 31 books, 40 scientific papers, and more than 400 articles addressing geology, geography, speleology, tourism, environmental sciences, history of science, history of art, music, environmental protection, civic issues, and public policy. He also produced scientific documentary scripts and delivered more than 500 public lectures, including broadcasts on radio and television.

A substantial part of his doctoral research was published under the same title and remains an authoritative reference in karst science. The volume represents a genuine treatise on karstology, supported by an extensive bibliography comprising nearly 900 references.

Figure 6. Karst Morphology (left), Global Tectonics (right)

The work provides a critical analysis of the physicochemical, lithological, tectonic, mechanical, and hydrogeological factors governing karstification processes and provides a comprehensive framework for understanding the mechanisms controlling karst development.

Bleahu was also the author of Global Tectonics (Fig. 6), published in two volumes (1983 and 1989), representing at the time one of the most comprehensive syntheses of plate tectonic theory ever produced by a single author. The work explains the formation of major geomorphological features through plate dynamics and includes applications relevant to the geology of the Romanian Carpathians (Bleahu, 1983–1989).

His lifelong conservation project was the establishment and promotion of the Apuseni Natural Park. The region's geological, geomorphological, biological, and cultural diversity, together with its exceptional karst landscapes, exerted a profound influence on Bleahu, motivating decades of scientific research.

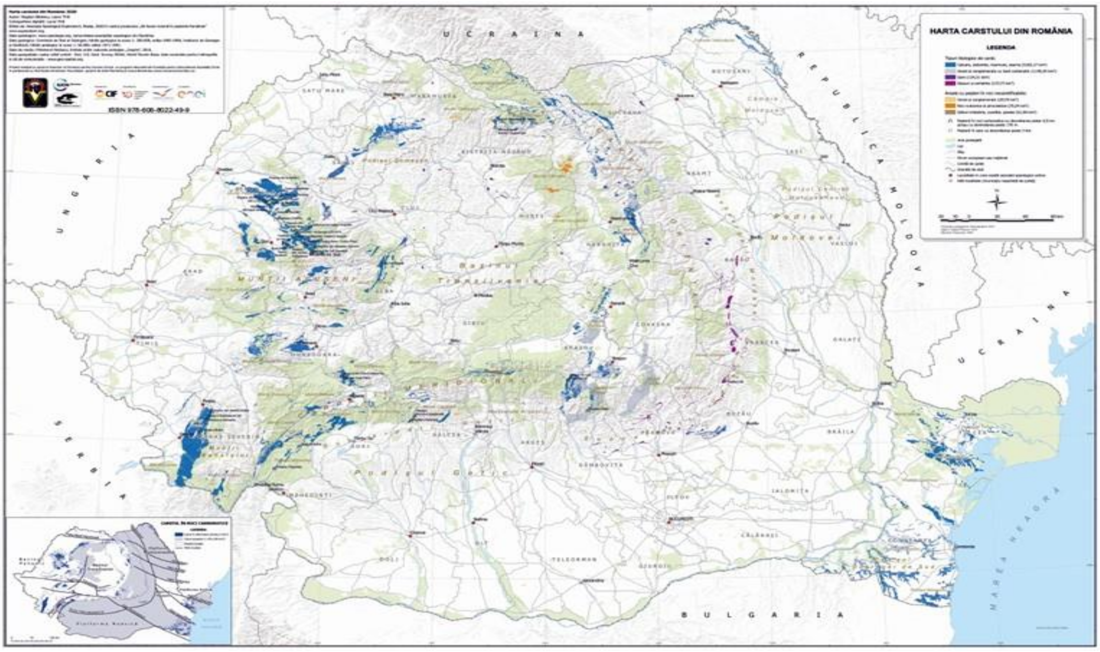
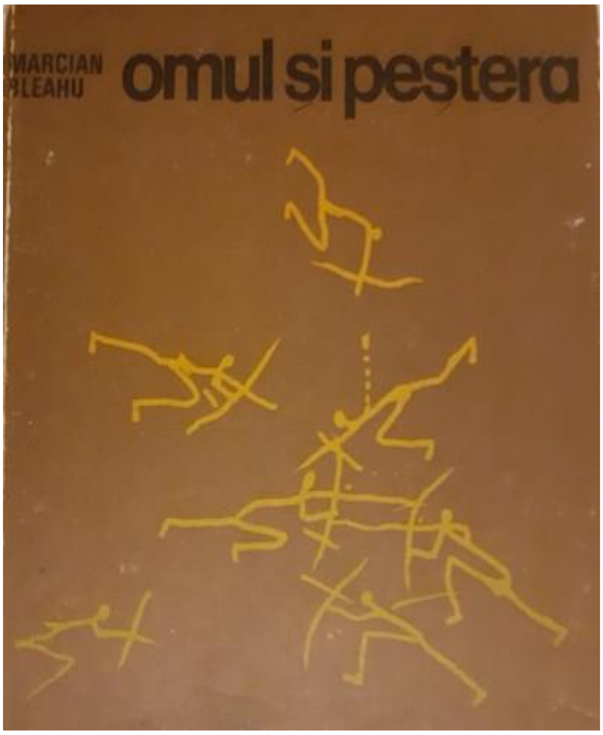


Figure 7. Karst Map of Romania (Bădescu & Tîrlă, 2020)



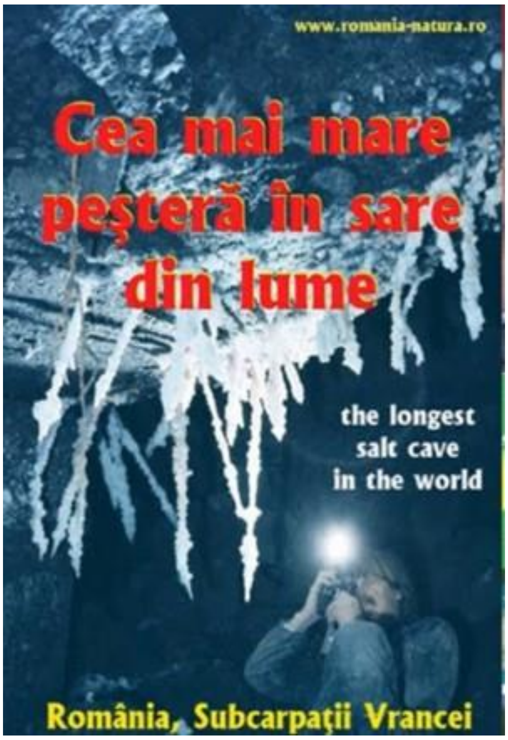


Figure 8. Man and the Cave (1978) (left), World's longest cave developed in salt deposits (between 1980 and 1992) (right)

Among the Romanian caves that became subjects of extensive speleological and karstological investigations are Bulba Cave, Scărișoara Ice Cave, and Buhui Cave.

In 2024, marking the centenary of Marcian Bleahu's birth, the Vrancea Branch of the Romanian Geographical Society organised a commemorative event in his honour. On this occasion, the Romanian Federation of Speleology presented recent achievements, heritage discoveries, and scientific developments of common interest.

The quality and scientific significance of the Federation's activities have been recognised through awards for cave and karst mapping projects at both national and international levels, including world titles obtained at congresses of the International Union of Speleology (UIS) in Switzerland (1997) and the United States (2009) (Bleahu et al., 2019–2023).

Recent contributions include the Karst Map of Romania (2020 Edition) (Fig. 7), developed within the project "Bringing Light into Romania's Caves", the Young Speleologist's Handbook, and innovative projects involving LiDAR cave scanning and virtual cave tours (Asociația Speologică Exploratorii, n.d.).

Through their continued efforts, Romanian speleologists demonstrate the essential role of geography and speleology in scientific knowledge, exploration, research, heritage valorisation, mountain rescue, and cave rescue activities.

Modern cave exploration is an interdisciplinary endeavour that integrates thematic cartography, identification of karst-prone terrains, groundwater tracing techniques, Geographic Information Systems (GIS), spatial modelling, and 3D visualisation within a geomorphological context.

Several major exploratory projects remain ongoing, including investigations in Vărășoaia Cave, Șura Mare Cave, Cernișoara Cave, Grind Shaft, and karst systems located in the Vrancea Subcarpathians.

A notable recent achievement is the Paul Matoș Hall within the Vărășoaia Cave, with an estimated volume of approximately 1.5 million cubic meters[1]. While Vântului Cave currently exceeds 50 km in surveyed passages and remains Romania's longest cave (Romanian Federation of Speleology, 2015), ongoing exploration suggests the potential discovery of even larger cave systems.

[1] The Humpleu system, with a development of over 41 km and a total elevation difference of 320m, has 4 of the largest halls in Romania: 1. Giants' Hall (750/111/35 m), 2.8 million cubic meters, the second largest in Europe; 2. Gabor Hallasi Hall (490/103/35 m) 1.3 million cubic meters; 3. Dance Hall (304/77/55 m) 0.48 million cubic meters; 4. Dan Coman Hall (242/73/23 m) 0.41 million cubic meters (Romanian Federation of Speleology, 2001).

Figure 9. Movile Cave - siphon sulfurous water (team Sarbu Serban): upper gallery, Lepthyphantes constantinescui, Cryptos speleorex, Trachelipus

Grind Shaft, located beneath Grind Peak in the Piatra Craiului Ridge, currently holds Romania's national depth record. Following more than 34 years of exploration, a vertical extent of –815 m was reached in 2025 (Institutul de Speologie „Emil Racoviță", n.d.). The system has been documented through integrated topographic representations, including terrain models, vertical profiles, and altimetric analyses.

Once again, cave exploration continues to reveal exceptional scientific and natural values hidden within previously unknown geographic spaces.

Such knowledge should be disseminated not only among specialists but also to the wider public, enabling society to benefit from the scientific, educational, and cultural significance of speleological discoveries.

Among Marcian Bleahu's most influential publications are: Conquerors of Darkness (1976), Man and the Cave (1978), (Fig. 8), Karst Landforms (1982), Protected Areas and Nature Conservation (2019)

While celebrating discoveries, we should also remember several landmark achievements of Romanian speleology that remain relatively unknown to the public.

According to the Bulletin of the International Union of Speleology (UIS):

> "*In Eastern European countries possessing extensive rock-salt and potash deposits, large-scale speleotherapy centres have been established*."

Romania occupies a unique position globally through the exceptional diversity of lithologies hosting caves, a fact that remains largely unknown outside the speleological community.

The Emil Racoviță Speleological Club of Bucharest achieved a world record through the discovery and exploration of the 6S Cave at Mânzălești, located on the Meledic Plateau in the Vrancea Subcarpathians. Between 1980 and 1992, it was recognised as the world's longest cave developed in salt deposits (Fig. 8), a status officially acknowledged during the 10th UIS Congress in Budapest (1989) (Marunteanu & Ioane, 2010).

Movile Cave (Fig. 9), discovered in Southern Dobrogea in 1986, is considered one of the most significant caves worldwide[2]. Its scientific importance stems from a unique ecosystem sustained by sulfur-based chemosynthesis, attracting international attention, including that of NASA researchers.

The ecosystem is believed to have remained isolated from the surface environment for approximately 5.5 million years, representing one of the most extraordinary natural laboratories for the study of life in extreme environments. Life in the cave is represented primarily by microbial mats (bacteria) on the

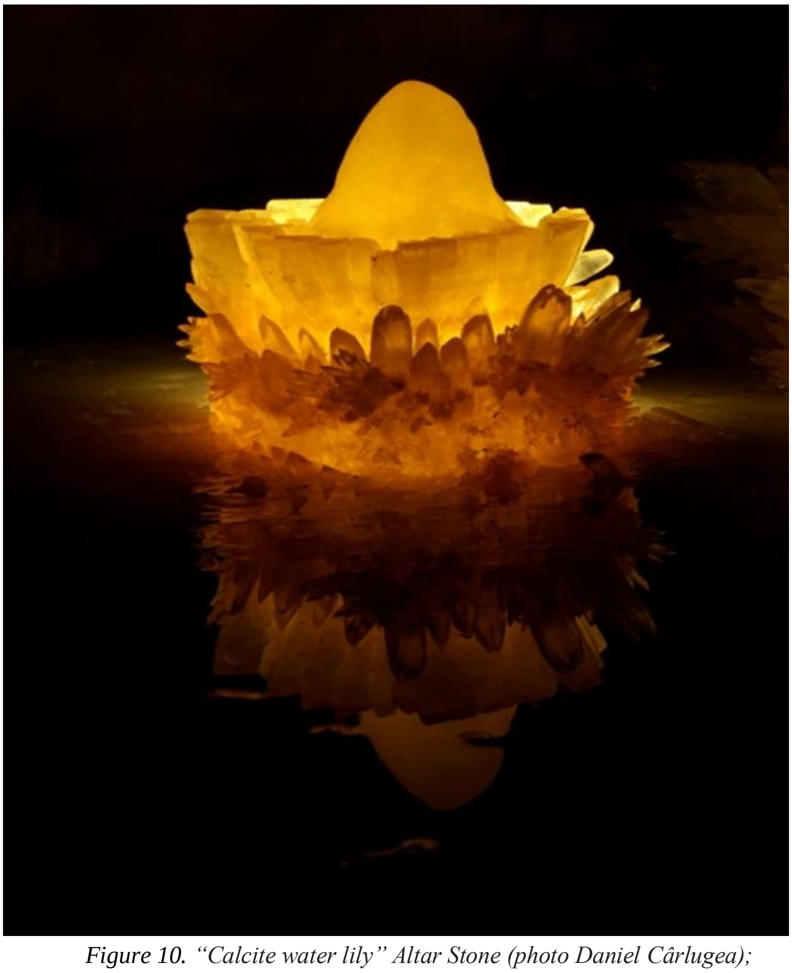


Figure 10. "Calcite water lily" Altar Stone (photo Daniel Cârlugea);

[2] 27th International Conference on Subterranean Biology. (2026). ICSB 2026. https://icsb2026.com/

cave walls and the surface of pools, based on chemosynthesis (Sarbu et al., 1996).

Piatra Altarului Cave (Fig. 10), discovered in 1984 in the Bihor Mountains (Societatea Română de Speologie, n.d.), was closed shortly after its discovery due to its outstanding scientific and aesthetic value. Over 90% of all calcite cave formations described in the literature are found here. Its exceptional remarkable abundance and diversity of speleothems within a relatively small area have earned it international recognition among cave scientists.

Figure 11. Coliboaia Cave, woolly rhinoceros, ca. 34,000-36,000 years B.C. (photo Posmoșanu Andrei)

Coliboaia Cave (Fig. 11), located in the Apuseni Mountains, contains prehistoric parietal art attributed to the Aurignacian or Gravettian cultural horizons and dated between approximately 32,000 and 36,000 years before present (Muzeul Țării Crișurilor. Crisia, XLI, 2011).

Together with the paintings of Chauvet Cave in France, the Coliboaia artworks represent some of the earliest known artistic manifestations of modern humans in Europe (Clottes et al., 2013).

The depiction of a woolly rhinoceros, estimated at between 23 000 and 35 000 BP (Gravettian or Aurignacian), is among the most remarkable examples of Paleolithic cave art discovered in Romania (UNESCO World Heritage Centre, 2024).

The exploration of Romania's karst regions continues to reveal invaluable scientific information and cultural heritage. This ongoing endeavour is driven by dedicated researchers and explorers who demonstrate professionalism, ethical conduct, scientific rigour, and courage, making significant contributions to both Romanian and international geography, speleology, and Earth sciences.

Competing interests

The authors declare that they have no competing interests.

References

Romanian Geographical Society. (n.d.). The Romanian Geographical Society and the modernization of Romania. https://geo-sgr.ro/the-romanian-geographical-society-and-the-modernization-of-romania/

Romanian Federation of Speleology. (n.d.). Romanian Federation of Speleology. https://www.frspeo.ro/

Tabacaru, I. G., & Danielopol, D. L. (2020). The remarkable history of the "Emil Racoviță" Institute of Speleology (1920–2020): From ideas initiated at "Laboratoire Arago" in France to the successful research in Romania. Vie et Milieu – Life and Environment, 70(2), 89–97. https://doi.org/10.57890/k6y9wt22

Onac, B. P. (2019). Marcian D. Bleahu (1924–2019). International Journal of Speleology, 48(3), 311–312. https://doi.org/10.5038/1827-806X.48.3.2295

Onac, B. P., Viehmann, I., Lundberg, J., Lauritzen, S.-E., Stringer, C., & Popiță, V. (2005). U–Th ages constraining the Neanderthal footprint at Vârtop Cave, Romania. Quaternary Science Reviews, 24(10–11), 1151–1157. https://doi.org/10.1016/j.quascirev.2004.12.001

Bleahu, M. D. (1983–1989). Tectonica globală (Vols. 1–2). Editura Științifică.

Bleahu, M., Perlik, R. A., Aldica, G. V., Minghiraș, T., Pop, R., Cazan, G., & Bușu, L. (2019–2023). „10.000” (Vols. 1–3). Editura Art Soleil.

Bădescu, B., & Tîrlă, L. (2020). Harta carstului din România [The Karst Map of Romania]. Asociația Speologică Exploratorii. https://www.exploratorii.org/wp-content/uploads/2020/09/Harta-carstului-din-Romania.pdf

Asociația Speologică Exploratorii. (n.d.). Scanare 3D. https://www.exploratorii.org/scanare-3d/

Romanian Federation of Speleology. (2001). Speomond (No. 6). https://www.frspeo.ro/wp-content/uploads/2015/08/speomond-06.pdf

Romanian Federation of Speleology. (2015, September 10). Speologia explorativă în România. https://www.frspeo.ro/speologia-explorativa-in-romania/

Institutul de Speologie „Emil Racoviță”. (n.d.). Avenul de sub Vârful Grind. https://www.speologie.org/avenul-de-sub-varful-grind

Marunteanu, C., & Ioane, D. (2010). Salt karst in Manzalesti, Romania. In Niki Evelpidou, Tomás de Figueiredo, Francesco Mauro, Vedat Tecim, & Alexis Vassilopoulos (Eds.), Natural heritage from East to West: Case studies from six EU countries (pp. 105–109). Springer. https://doi.org/10.1007/978-3-642-01577-9_13

Sarbu, S. M., Kane, T. C., & Kinkle, B. K. (1996). A chemoautotrophically based cave ecosystem. Science, 272(5270), 1953–1955. https://doi.org/10.1126/science.272.5270.1953

Societatea Română de Speologie. (n.d.). Peștera Piatra Altarului. https://www.speologie.org/pestera-piatra-altarului

Muzeul Țării Crișurilor. Crisia, XLI. (2011). Muzeul Țării Crișurilor. https://crisia.mtariicrisurilor.ro/wp-content/uploads/2024/12/41-Crisia-Muzeul-Tarii-Crisurilor-XLI-2011_compressed.pdf

Clottes, J., Besesek, M., Gély, B., Ghemiș, C., Kenesz, M., Lascu, V. T., Meyssonnier, M., Philippe, M., Plichon, V., Prud'homme, F., Radu, V. A., Rus, T., & Tociu, R. L. (2013). The discovery of a new Paleolithic decorated cave in Romania (Bihor Department). In J. Clottes (Ed.), Pleistocene art of the world: Proceedings of the IFRAO Congress, Tarascon-sur-Ariège, September 2010 (pp. 513–528). Palethnologie, 5. https://doi.org/10.4000/palethnologie.2821

UNESCO World Heritage Centre. (2024). Romania's caves (Tentative List No. 7011). UNESCO. https://whc.unesco.org/en/tentativelists/7011/

Analysis of the Dynamics of Changes in Soil–eluvial Formations Across the Main Bioclimatic Zones of the Aragats Mountain Massif

Georgian Geographical Journal, 2026, 6(1) 14-20

DOI:
https://journals.4science.ge/index.php/GGJ

Hasmik Balyan[1,*], Varduhi Margaryan[1], Ekaterina Gaidukova[2], Sargis Sargsyan[1]

[1] Faculty of Geography and Geology, Yerevan State University

[2] Russian State Hydrometeorological University, Saint Petersburg, Russian Federation

* Corresponding author: hbalyan@ysu.am

Citation: Balyan, H.; Margaryan, V.; Gaidukova, E.; Sargsyan, S. Analysis of the Dynamics of Changes in Soil–eluvial Formations Across the Main Bioclimatic Zones of the Aragats Mountain Massif. *Georgian Geographical Journal* 2026 6(1), 14-20. https://doi.org/10.52340/ggj.2026.06.01.03

Abstract

The aim of this study is to examine the sequence of soil–eluvial formations using the Aragats Mountain Massif as a representative example. The differentiation of these formations is primarily governed by the influence of bioclimatic factors. Primary soil–eluvial formations, commonly referred to as soil eluvium, are regarded as integrated complexes comprising weathering crusts and soils formed under natural landscape conditions. In Armenia, however, investigating such formations poses a considerable challenge. Owing to centuries of human activity and land use, a substantial proportion of primary soil–eluvial complexes has been either destroyed or significantly transformed. Only in limited areas have soil eluviums retained their original characteristics or remained relatively intact.

Keywords: soil–eluvial formations, bioclimatic factors, weathering crust, belozem, carbonate crust

Introduction

According to B.B. Polynov's interpretation, the term "weathering crust" is a key concept and subject for loose detrital deposits, where primary rocks forming the upper part of the lithosphere continuously change under the influence of weathering processes. According to E. Shantser, weathering crust coincides with the definition of "eluvium." B.B. Polynov called "residual," i.e., unredeposited, referred to the residual weathering crust using this term. The formation of eluvium, the composition of its constituent formations, and its thickness vary depending on climatic conditions (a combination of temperature and humidity).

Currently, principles for classifying agrolandscapes have been formulated, taking into account zonal affiliation, the nature of crop rotations, their biogeochemical structure, and migration processes in catenas (Perelman & Kasimov, 1999; Kasimov, 2013). The simplification of the biogeochemical structure of agrolandscapes compared to natural ones determines their lower stability, and maintaining it requires ensuring the necessary diversity and preserving the ecological framework (Glazovskaya, 1992; Nikolaev & Kopylov, 2004). The effects of the mutual influence of elements depend on the type of crops and migration conditions (Environmental Geochemistry, 1990; Glazovskaya, 2007).

In mountainous terrain (Gevorgyan, 2006), where vertical zonality is strongly pronounced, the distribution of main bioclimatic factors, the development and changes in soil cover occur completely differently compared to lowland areas. Studying all stages of landscape formation makes it possible to understand how certain features (in particular, soil-ground) arose. And, undoubtedly, each landscape component should be studied within a dynamic framework.

In general, eolian processes in Armenia occurred under structural-morphological and hydrothermal conditions that, with active water exchange, contributed to the formation of acidic and slightly acidic solutions, thereby facilitating the rapid migration of chemical elements and oxidation of metallic elements (Balyan, 1982; Balyan & Hayrapetyan, 1979). These processes directly affected the products of primary weathering materials and their redistributed varieties, endowing them with specific geochemical characteristics.

Comparison of the content of chemical elements in primary rocks and, accordingly, in the varieties of the weathering crust showed the degree of their accumulation and redistribution.

The study aims to investigate the sequence of soil-eluvial formations of the Aragats mountain massif under the influence of the bioclimatic factor.

Methods and Materials

To achieve the objectives of this study, relevant published works (Bargagli, 2005; Bashkin & Kasimov, 2004; Vinogradov, 1998; Dobrovolsky, 1979, 1998; Margaryan et al., 2022) were taken as a methodological basis. The Aragats mountain massif is a suitable object for the present study due to the large amplitude of changes in bioclimatic conditions caused by vertical zonality, and the presence of primary soil-eluvial formations or massive crystalline rocks of similar composition.

This allows considering the sequence of primary soil-eluviums from the subnival to the dry subtropical belt, developed on rocks of the Aragats mountain massif of andesite-basaltic and andesite-dacitic compositions, more or less altered by post-magmatic processes.

Here, three main bioclimatic belts with characteristic types of primary soil-eluvial formations are distinguished. Research was conducted along the Ashtarak – Agarak – Byurakan – Mount Aragats profile, as this profile traverses all landscape-climatic belts of the Aragats mountain massif. They are grouped into three main bioclimatic belts, based on the conditions of formation of primary soil-eluviums.

It should be noted that the identified bioclimatic belts correspond to generally accepted geomorphological altitudinal stages: the near-summit belt, the middle belt, and the lower belt.

In field conditions, profiles were constructed in the most suitable places to identify the interaction of residual and redeposited or buried under effusive weathering crusts, and a sufficiently large number of samples were taken from characteristic sections, mainly from eluvium and their redeposited varieties.

The following methods were used to study the selected samples: comparative, soil-geographical, morphological-genetic, profile, fractional, bulk-chemical, etc.

Mineralogical and morphological analyses were used to process the collected samples, mainly from eluvium and redeposited varieties of rocks and soils. The content of trace elements in the samples was determined by spectral analysis, according to which landscape-geochemical coefficients were calculated: Clarkes of concentrations, ratios of trace elements characterising certain geochemical processes, etc.

Mineralogical and chemical data obtained from X-ray diffraction analyses were subsequently processed.

It should be noted that the general methodological principles for studying landscape geochemistry also include historicism and a dynamic approach, as the formation of the modern landscape (and, in particular, the active agent of the landscape spectrum – the soil cover) is often associated with events of the distant geological past.

Retrospective analysis may further allow predicting the dynamics of development of the investigated soil-eluvial formations in the direction of degradation due to the spontaneous course of natural processes under the influence of the bioclimatic factor.

Studies were conducted in the three identified bioclimatic belts with characteristic types of primary soil-eluvial formations: the near-summit belt, located above 2600–2800 meters; the middle belt, located below, approximately at elevations up to 2000–2500 m; the lower belt, occupying the foothills of the southern and southwestern slopes of Mount Aragats, up to an altitude of approximately 1500–2000 m.

The research results were obtained based on processed samples collected in the field. The obtained materials serve as visual confirmation of the general position on soil-eluvial formations, as well as soils, as a mirror and memory of landscapes, and further, on the weathering crust itself, developed in natural landscapes.

Results and Discussions

As already noted, the three main bioclimatic belts studied are arranged in the following order. The near-summit belt is located above 2600–2800 m above sea level. Weathering and soil formation conditions here are harsh. The climate is cold, with frequent temperature drops below 00 C in all months of the year. Precipitation is about 800–1000 mm or more (Table 1). The middle belt is located below the near-summit belt at elevations up to 1600–2600 m. The climate is moderately cold and cold. Precipitation is approximately 600–800 mm. The lower belt occupies the foothills of the southern and southwestern slope of Mount Aragats up to an altitude of 1500–2000 m. The climate is characterised as continental, moderately warm, dry, with an annual precipitation of 400–600 mm.

Table 1. Values of average monthly and maximum air temperatures at meteorological stations for their entire period of operation

Meteorological station	Elevation above sea level, m	Months											
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
		Air temperature, °C											
Aragats H.M. Station	3229	-2,62	-1,82	2,50	8,03	12,2	15,8	18,6	18,4	14,9	9,45	4,05	-0,38
Amberd	2071	-7.2	-6.0	-2.1	4.4	9.6	13.8	18.0	18.2	14.0	7.7	1.2	-4.6
Ashtarak	1090	-4.2	-1.3	4.4	11.3	16.2	20.8	24.7	25.0	20.2	13.6	6.6	-0.5
		Atmospheric precipitation, mm											
Aragats H.M. Station	3229	72.7	78.2	91.9	106.0	105.8	79.7	67.8	47.5	38.5	65.7	77.1	71.6
Amberd	2071	62.5	63.4	66.9	81.2	99.3	56.4	34.4	21.9	23.1	53.8	55.0	60.4
Ashtarak	1090	26.3	28.3	34.8	50.0	55.1	33.5	20.4	12.1	15.0	32.2	29.1	29.2

Soil-eluviums of the near-summit belt. The harsh, sufficiently humid climate, with the absence of a frost-free period and frequent temperature transitions through the freezing point of water in the summer months, leads to the development of mainly frost weathering mechanisms here. That is, the process of rock destruction occurs under the wedging effect of freezing water. It is known that when the temperature drops below 0°C, water located in the system of large rocks freezes first. Water filling capillary, microcapillary cracks during the summer do not have time to freeze completely, and only partially freeze in winter. This contributes to the formation of large blocky and blocky material for eluvium and a relatively small amount of fine-grained material. The absence of a frozen phase in eluvium significantly changes the usual type of moisture migration and stress distribution for other bioclimatic belts, which ultimately leads to the formation of various eluvial-blocky formations here, the so-called "chingil."

Eluvial blocks and rubble bear no visible traces of hypergene alteration. The fine-grained material in the cracks between the blocks consists of fragments and mechanically fragmented minerals of parent rocks: feldspars, glass, micas, etc. Clay minerals are present in the clastic grains. Based on optical observations and physical methods data, the clay component of eluvial fines consists mainly of associations of montmorillonite, hydromicas, and kaolinite.

As already noted, the main agent of change in parent rocks is frost weathering. The principal source of sodium (Na), most likely, is groundwater, i.e., the rate of weathering of Na-containing minerals is exceptionally low. Alkaline elements from this landscape belt are mainly removed, as low evaporation prevents their concentration. Considering that in the Quaternary period, Mount Aragats underwent twofold glaciation, the denudation products of which cover quite extensive areas in the form of seas, it should be assumed that in the composition of the eluvium of the near-summit plateau of Mount Aragats, a certain proportion of the aforementioned minerals are products of glacial denudation from the summit zone. It is interesting to note that outcrops of powerful red-yellow hydrothermally altered andesite-dacites are traced in the crater (glacial cirque) of Mount Aragats. Due to the denudation of these rocks on the near-summit plateau, powerful accumulations of Middle Quaternary moraines were formed, in the composition of which, along with undecomposed gray-violet loams, representing products of denudation of weakly decomposed dacites of the summit zone, there are interlayers of ocherous and dirty-yellow loams, which, obviously, represent products of redeposition of hydrothermal rocks or, possibly, exarational denudation of ancient crust. In the Middle Pliocene, intense crust formation processes developed on the Armenian volcanic highlands under hot climatic conditions. In confirmation of this, the fact of pollen of Cimmerian appearance (magnolia, etc.) discovered by him in the weathering crust of the Vardenis highlands is cited. Apparently, similar conditions existed on Mount Aragats, and the redeposited ocherous layers may belong to this ancient crust or are a product of the denudation of the hydrothermal zone of the summit belt of Mount Aragats. Answers to these questions can be obtained by a detailed study of the spatial position and vertical section of the moraines of the near-summit plateau.

In the composition of the modern soil-eluvium of the near-summit plateau, the presence of highly decomposed minerals (kaolinite, metahalloysite, etc.) indicates to some extent that the formation of soil-eluvium on the near-summit plateau of Mount Aragats developed not on fresh parent rocks of andesite, andesite-dacite compositions, but on a deep Middle Quaternary exarational cut, which preserved in the rock fissures an ancient allochthonous crust, or products of hydrothermally altered rocks brought by glaciers from the summit zone.

Soil-eluviums of the middle belt. Within the middle belt, on the slopes of Mount Aragats with a steepness of up to 20–25°, the weathering crust has significant differences from the weathering crust of the previous belt. Here, primary soil-eluvial formations are formed by chemical and biochemical weathering mechanisms. In the structure of the weathering crust itself, two zones are clearly distinguished: the lower, saprolite zone, the thickness of which, according to drilling data, does not exceed 10 m. On the slopes, due to deforestation, soil and the upper loose parts of the saprolite zone are usually eroded. A typical example of this type of weathering crust can be found on the southern slope of Mount Aragats, at an altitude of about 2300 m above sea level, somewhere near the village of Voskevaz nomad camp. Under conditions of a weakened periodic leaching moistening regime, a significant part of the elements is removed. Active migrants include alkaline and alkaline-earth elements. They are carried beyond the described belt of the weathering crust and can serve as an additional source of carbonates for the illuvial horizons of the lower belt. Iron, aluminium, and silicon remain in the eluvium and participate in the construction of synthetic hypergene neoformations. Carbonates are practically absent or occur in the lower horizons of the weathering crust of subordinate landscapes. In the saprolite zone, hypergene neoformation elements are represented by silicified iron hydroxides, as well as metahalloysite. Newly formed products fill primary and secondary pores and cracks in the eluvium. Their distribution is uneven. Judging by experimental materials, neoformations of this type are found throughout the weathering crust profile. Active migrants are alkaline and alkaline-earth elements, as well as silica. And here, hypergene mineral neoformations appear: halloysite-metahalloysite minerals in the lower parts of the soil-eluvium and montmorillonite in the upper parts.

Primary soil-eluvial formations of the lower belt are characterised by relatively weak chemical, physical, and physicochemical processes due to a sharp weakening of moistening. As an example, we can consider the weathering crust and the soil developed on it on andesite-basalts 2 km from the village of Agarak (along the Ashtarak–Byurakan road). Two genetic horizons are distinguished in the weathering crust: an eluvial rubbly-loamy horizon with plant roots 0.5–0.6 m thick and an illuvial blocky horizon with abundant white carbonate material excretions along the cracks (thickness 2–3 m). The upper loamy-rubbly horizon of the soil-eluvium is usually destroyed by erosion, and illuvial whitish carbonate horizons, which received the local name "belotsvetnaya" (white-colored), emerge to the surface.
Fractured andesite-basalts within the lower illuvial-carbonate horizon of the soil-eluvium show no visible traces of chemical destruction on the surface. This excludes the assumption of an autochthonous origin of carbonate accumulations. Carbonate excretions are found in the lower parts of the loamy-rubbly horizon, where it has been preserved. Further down the profile, the amount of carbonate substance increases. Dense and powdery carbonate crusts occur, and areas of carbonate cementation appear.
Thus, the clearly expressed contact of the carbonate crust with completely fresh effusives indicates not an eluvial, but rather an allochthonous origin. In addition, the very fact of the development of such powerful carbonate deposits (0.5–3.0 m) of various generations on effusives excludes the possibility of assuming their formation solely at the expense of andesite-basalts, which do not contain so many carbonates in their composition.

The question of the genesis of the so-called "belozems" is analysed and highlighted in detail in the author's work (Balyan et al., 1975), as these light-colored carbonate soils, developed on effusives of the entire Armenian volcanic highlands, have long been a subject of discussion. It is known that the carbonate crust and its products are developed mainly in arid and semi-arid regions on low slopes and foothill plateaus.

However, at the same time, they do not show a direct genetic connection with the parent effusives. Given that they are significantly older formations, their genesis may be related to the period of intense development of Quaternary volcanism, with the release of huge masses of carbon dioxide from numerous eruptive apparatuses abundant around the Mount Aragats massif. The saturation of surface waters with aggressive carbon dioxide contributed to the deposition of carbonate flowstone crusts on effusives.

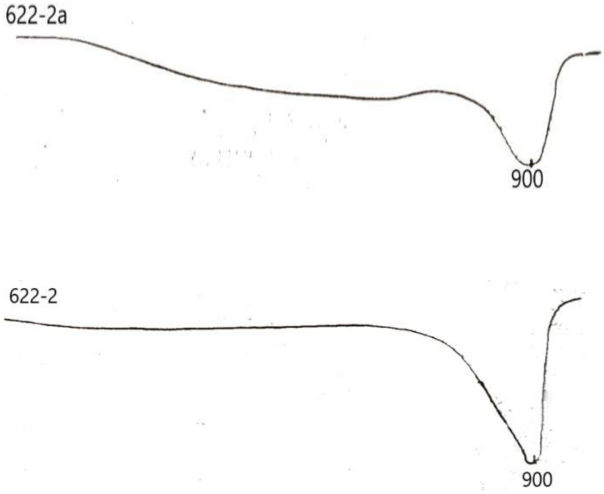


Figure 1. Thermograms of material from the weathering crust of andesite-basalts in the lower belt of Mount Aragats. 1-2 carbonate segregations, white powdery and grey porcelain-like areas, respectively. 1-2 – bulk samples

1. 2.

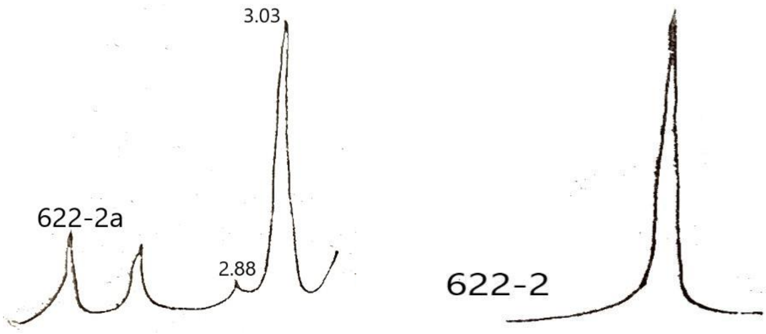


Figure 2. Diffractograms of material from the weathering crust of andesite-basalts in the lower belt of Mount Aragats. 1 – white powdery carbonate. 2 – grey porcelain-like carbonate

Based on thermal (Fig. 1, curves 1 and 2) and X-ray (Fig. 2, curves 1 and 2) analyses, the carbonate segregations are represented by calcite. The X-ray method detected a clay phase of montmorillonite with a small amount of hydromica and chlorite in the insoluble residue. Already below 2-3 m from the surface, carbonate segregations, as well as other products of supergene alteration of the rock, practically disappear.

According to X-ray and thermal analyses (Fig. 1, curves 1 and 2 and Fig. 2, curves 1 and 2), the eluvial crusts mainly contain a complex of minerals characteristic of the parent rock. The absence of any relict soil-eluvial formations of a different composition and structure in the described landscapes suggests that "white-colored" soil-eluvians developed over a very long period, at least for most of the Quaternary period.

Figure 3. Salinization

The system of primary soil-eluvial formations of Mount Aragats and the adjoining Ararat plain represents an area of salt accumulation with a progressively increasing series of salinisation (Fig. 3), occurring due to the weathering of basic massive-crystalline rocks rich in alkali and alkaline earth elements and infiltration of groundwater.

Conclusion

In the summit bioclimatic belt of Mount Aragats, eluviums are mainly dominated by coarse blocky material, and an independent soil zone is not distinguished. The main agent of parent rock alteration is frost weathering.

The clay phase is inherited from hydrothermal alteration of rocks and is represented by the association: hydromica-montmorillonite.

The principal source of sodium (Na) is most likely groundwater, as the weathering rate of Na-containing primary minerals is extremely low.

In the middle belt, primary soil-eluvial formations are formed by chemical and biochemical weathering mechanisms. They consist of two distinctly expressed zones: saprolite and soil. Hypergene mineral neoformations appear here: halloysite and metahalloysite minerals in the lower parts of the soil-eluvians and montmorillonite in the upper parts.

The primary soil-eluvial formations of the lower belt are characterised by relatively weak chemical and physicochemical processes. The thin blocky soil-eluvium has a differentiated profile with a leached and carbonate horizon.

A number of signs of the mineral part of the soil-eluvians, as well as historical and archaeological data, suggest that weathering and soil formation on the slopes of the middle and lower belts of Mount Aragats occurred under forest communities, which are primary here. This is one of the positive factors ensuring the prospects for planned reforestation work in the republic.

The results indicate that in the landscapes of the summit belt, Na is an active migrant, supplied by infiltrating groundwater, as chemical and physicochemical weathering is not developed. The sodium supplied with the water does not linger in the soil-eluvians of this belt. This element does not affect the soil-eluvians of the underlying landscapes down to the lower belt. Unlike calcium, the bulk of which is formed in the middle belt. Along with calcium mobilised in situ, it forms carbonate neoformations here.

The system of primary soil-eluvial formations of Mount Aragats and the adjoining plain represents an area of salt accumulation with a progressively increasing series of salinisation.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

All authors provided critical feedback and helped shape the research, analysis and manuscript.

ORCID iD

Hasmik Balyan *https://orcid.org/0009-0006-9911-7824*
Varduhi Margaryan *https://orcid.org/0000-0003-3498-0564*
Ekaterina Gaidukova *https://orcid.org/0000-0002-3547-5538*
Sargis Sargsyan *https://orcid.org/ 0009-0005-7570-8091*

References

Avessalomova, I. A. (2007). Biogeochemistry of landscapes. Moscow State University Press.

Balyan, A. S. (1982). On the paleogeography of Quaternary loose-detrital formations of the Aragats Massif. Uchenye Zapiski Yerevan State University, (2), 130–136.

Balyan, A. S., & Hayrapetyan, T. A. (1979). On the origin and paleogeographical development of whitish soils in Armenia. Uchenye Zapiski Yerevan State University, (1), 103–113.

Balyan, A. S., Hayrapetyan, T. A., Chernyakhovsky, A. G., Balyan, A. O., & Gradusov, B. P. (1975). Primary soil–eluvial formations of the main bioclimatic belts of the Aragats Mountain Massif. Proceedings of the Academy of Sciences of the Armenian SSR, Earth Sciences, 28(2), 78–93.

Bargagli, R. (2005). Biogeochemistry of terrestrial plants. GEOS.

Bashkin, V. N., & Kasimov, N. S. (2004). Biogeochemistry. Nauchny Mir.

Dobrovolsky, V. V. (1979). Scattered metals in nature. Znanie.

Dobrovolsky, V. V. (1998). Fundamentals of biogeochemistry: Textbook for geographical, biological, geological, and agricultural specialties of universities. Vysshaya Shkola.

Environmental geochemistry. (1990). Nedra.

Gevorgyan, F. (2006). Exodynamic weathering system in the territory of the Republic of Armenia. In Geographical science in Armenia: Present and future. Proceedings of the scientific conference dedicated to the 70th anniversary of the foundation of the Armenian Geographical Society (pp. 167–177). Yerevan State University Press.

Glazovskaya, M. A. (1992). Biogeochemical organization of ecological space in natural and anthropogenic landscapes as a criterion for their stability. Izvestiya Rossiiskoi Akademii Nauk. Seriya Geograficheskaya, (5), 5–12.

Glazovskaya, M. A. (2007). Geochemistry of natural and technogenic landscapes. Moscow State University Press.

Kasimov, N. S. (2013). Ecogeochemistry of landscapes. IP Filimonov M. V.

Margaryan, V. G., Avetisyan, G. D., Sargsyan, A. T., & Margaryan, P. N. (2022). Patterns of spatio-temporal distribution of absolute minimum near-surface air temperatures in the Lake Sevan Basin. Izvestiya Rossiiskoi Akademii Nauk. Seriya Geograficheskaya, 86(2), 232–242. https://doi.org/10.31857/S2587556622020078

Nikolaev, V. A., & Kopyl, I. V. (2004). Landscape ecology of agricultural lands. In Geography, society, environment (Vol. 2, Functioning and current state of landscapes, pp. 257–268). Gorodets Publishing House.

Perelman, A. I., & Kasimov, N. S. (1999). Landscape geochemistry. Asteria-2000.

Vinogradov, B. V. (1998). Fundamentals of landscape ecology. GEOS.

Natural Events Related to Hydrological Processes and Ways to Avoid Them in the Tourist Area of Adjara

Sophio Gorgijanidze[1*], Gocha Jincharadze[1], Mikhael Pipia[1], Mirian Silagadze[2], Zaza Gulashvili[3], Nazibrola Beglarashvili[1], Natela Kobakhidze[1]

[1] Institute of Hydrometeorology of the Georgian Technical University, Tbilisi, Georgia

[2] Ministry of Environmental Protection and Agriculture of Georgia, Tbilisi, Georgia

[3] Institute of Geography, Ivane Javakhishvili Tbilisi State University, Tbilisi, Georgia

* Corresponding author:

Georgian Geographical Journal, 2026, 6(1) 21-28

DOI:
https://journals.4science.ge/index.php/GGJ

Citation: Gorgijanidze, S.; Jincharadze, G.; Pipia, M.; Silagadze, M.; Gulashvili, Z.; Beglarashvili, N.; Kobakhidze, N. Natural Events Related to Hydrological Processes and Ways to Avoid Them in the Tourist Area of Adjara. *Georgian Geographical Journal* 2026, 6(1), 21-28. https://doi.org/10.52340/ggj.2026.06.01.04

sophiogorgijanidze@gmail.com

Abstract

Tourism is one of the world's priority economic sectors. It plays an important role in the country's economic and social development, which is an important direction of sustainable development. Georgia is distinguished by its tourism potential. Its natural conditions and historical and ethnographic landmarks contribute to the development of tourist-recreational resources. In Georgia, the Achara region is distinguished by the beauty of the Black Sea coast and mountainous regions. According to geostat data, the region is visited annually by more than 2 million visitors. It is also important to consider the natural events that occur every year in Achara against the background of climatic warming and cause considerable damage. This has a negative effect on the tourism sector of the region. In addition, Achara is distinguished by the abundance of atmospheric precipitation. As a result, Floods and debris flows occur frequently (2002, 2005, 2007, 2012, 2022 and 2023). There are many examples of them. Therefore, it is necessary to observe the natural hydrological events that occur in the Achara region. Understanding their mechanisms and analysing their frequency are essential for hazard forecasting. Such a forecast, depending on the seasons of the year, will lead to positive results in the future for the tourist potential and sustainable development of tourism in the administrative unit of Achara.

Keywords: hydrology, flood, debris flow, atmospheric precipitation

Introduction

Tourism means traveling for vacation, spending free time or business purposes. It is one of the priority fields in the world. Vacation planning is an important process for any employed person. Today, tourism extends to virtually every part of the world. In high mountains, seacoasts, arctic or hot deserts. Today, tourism is one of the most global and popular industries, which is constantly dynamically growing and developing in different directions. This is the reason for the formation of different types and directions of tourism, because tourists have diverse interests, expectations and travel preferences, tastes, and needs, which must be satisfied with diverse tourist offers. It determines the economic and political situation of the country, which is an important direction of sustainable development. Therefore, it is necessary to study all the places, determine the expected threats and risks, to protect the residents and tourists there from the potential natural hazards.

It should be noted that Georgia is distinguished by its tourism potential. Its natural conditions and historical-ethnographic landmarks contribute to the development of touristic-recreational resources. Their intensive use began in 1960. Many tourist facilities were built to serve both local and foreign tourists. Until 1990, all districts were involved in tourism activities. The modern tourism development policy is aimed at fully utilizing and filling tourist facilities, which are presented in the form of hotels, family homes, hostels, camping sites and sanatoriums. At the same time, it was more developed, according to modern standards and the synthesis of historical culture. It is important that the local population is actively involved in the tourism industry, which increases the country's economic stability and demands.

For the first time, seven tourist regions were created in Georgia: Abkhazia, Adjara, Kolkheti, Shovi-Utsera, Borjomi-Bakuriani, Tbilisi and East Caucasus. Later, some districts were expanded. (Geography of Georgia, 2000) Over the years, all regions have been involved and are actively receiving the flow of tourists. This gives a big profit for the country's economy. Among these tourist regions, Adjara stands out, because the region has always fascinated visitors with the beauty of the Black Sea coast and mountainous regions. According to Geostat data, more than 2 million visitors visit the region every year, which makes the tourism-economic potential here increasingly important.

Figure 1. St. Batumi, multi-storey hotels (photo by A. Turmanidze)

According to the data of 2022-2023, the number of local and foreign visitors reached 1210.6 thousand visitors in 2022, and 2468.5 in 2023. The distribution of guests took place in 491 places of accommodation, while the number of guests in hotels was distributed to 1345.6 people (Fig. 1) (National Statistics Office of Georgia, n.d.).

But here we should mention the natural events that occur in Adjara every year against the background of climatic warming and cause many losses. This has a negative effect on the tourism sector of the region. In addition, Adjara is distinguished by the abundance of atmospheric precipitation (4500-5000 mm). They contribute to the development of landslides, rockfalls, floods and debris flows. Avalanches are also common in the mountains during winter. The years 2012-2016 were characterized by a lack of snow, during which many avalanches occurred in mountainous Adjara, causing destruction and damage. Unfortunately, there were also victims. These processes are happening both in the past and now. Batumi, the capital of Adjara, is significant, which is always flooded because of active storms over the years.

Study area

Adjara is historical-geographical region of Georgia, which is located in the valley of Acharistskali. The territory of the Adjara region has rich history. It was inhabited since ancient times. Except cultural monuments from different periods, there is wonderful nature here, in the form of sunny seacoasts and mountainous Adjara. The region has a humid subtropical climate. With warm winters and cool summers. Rivers are mostly fed by atmospheric precipitation. The flora and fauna are also diverse because both sea and mountain landscapes are represented.

Adjara is in the extreme south-west of Georgia, in the valley of the Acharistskali River, on the coast of the Black Sea. It is bordered by Guria in the north, Akhaltsikhe in the east, and the state of Turkey in the south. Its administrative center is Batumi. The Autonomous Republic of Adjara includes the municipalities of Batumi, Khulo, Keda, Kobuleti, Shuakhevi and Khelvachauri. The highest peak of Adjara is Mount Kanli (3007m), which is located on the Arsiani ridge. The main river of the region is Acharistskali. Its tributaries are: Kavreta, Khokhnistskali, Agaristskali, Chvanitskali, Chirukhistskali and Skhalta. Adjara also has rivers: Kintrishi, Chakvistskali, Korolistskali, which flow straight to the Black Sea. The Kobuleti-Chakvi ridge, which divides this side into mountainous and coastal zones, plays a decisive role in the formation of Adjara's microclimate. Due to its influence, coastal Adjara has a humid subtropical climate with warm winters and hot summers. In mountainous Adjara, the climate is less humid, and winters are generally less snowy. The average summer temperature in coastal areas is 22-24°C, in the mountains - 17-21°C. In winter, it is 4-6°C in the plains, 3-2°C in the highlands. This area is not rich in lakes, although we can see a few lakes (Maruashvili, 1954; Maruashvili, 1968; Maruashvili et al., 1971).

There are 4 protected areas in Adjara, and each one is characterized by individual and endemic varieties. Adjara is also rich in coastal and mountain resorts. Mountainous Adjara is especially fascinating, where sea and plain landscape mix. Tourist places are almost all over the spring and offer an unforgettable sight to the tourists. For example, Tago village is connected to Khulo district only by cable car (Georgian Travel Guide, n.d.) (Fig. 3).

Therefore, many different factors cause catastrophic events in the study area. Hence, the subject of our research is hydrological natural events in the Adjara region: floods and debris flow.

Data collection

Data were collected from the works and research of the Institute of Hydrometeorology. The material collected over the years formed the basis of numerous previous studies and articles. Data analysis was also done with the cooperation of the Environmental Protection Agency of Georgia. Important data are discussed in V. Tsomaia and S. Gorgijanidze's monograph on debris flow, where according to practical materials, expeditionary and annual studies, floods are determined throughout Georgia. which provides important information on the factors of occurrence of floods. Current flood information is available

Figure 3. Tourist facility in the village of Tago (1000 m) (photo by G. Jincharadze)

from a few information sources.

The facts

As we mentioned above, Adjara is characterized by an abundance of atmospheric precipitation. Against the background of climate change, it is important to know the negative consequences caused by their frequency. The frequency of natural hydrological events also depends on them, which creates a lot of problems for the region. During heavy rains, coastal flooding is frequent, which actively

Figure 4. Batumi, New Boulevard. February 17, 2017. (YouTube, n.d.)

damages the surrounding area. In addition, the infrastructure and tourist facilities located on the coast are damaged. The years 2002, 2005, 2007, 2012, 2022 and 2023 stand out, when storms and coastal flooding occurred several times during the year. The level of the Black Sea has risen significantly.

Adjara has risen by 22-25 cm during the last century, the result of which is that during the intrusion of the sea, the marine erosion has intensified along the coastline. And then brackish water causes bank erosion. If this includes agricultural fields and beaches, they are already severely eroded, easily flooded and destroyed by seawater. In addition, the power of storms is increased, seasonality also changes the characteristics of floods. Which is confirmed by many photo materials (Fig. 4).

The activation of landslides, which occurs almost every year, is also dangerous, as a result many residential buildings are damaged or destroyed, agricultural fields are damaged. Sometimes this process is accompanied by the blocking of riverbeds, which causes water stagnation. As a result, it is possible to breach a naturally dammed lake, which is accompanied by strong floods. A sharp increase in the level of the rivers in the entire valley is common, and the consequences of floods are always negatively reflected both in the mountainous Adjara and in the downstream of the rivers. Due to heavy rains, landslides often occur in valleys, and floods and debris flows occur on rivers. Such cases are

Figure 5. River Safristskali valley 2005 (photo by S. Gorgijanidze)

frequent, for example, in 2005, the flood occurred on the Safristskali River, which damaged the surrounding road, destroyed bridges and disabled highways (Fig. 5). Such an event was repeated in 2021 and again damaged the surrounding areas and roads (Fig. 6).

In 2007, because of a landslide in the village of Feria, the river was blocked, but for a short time. Unfortunately, the necessary works were not carried out immediately and the breakthrough of the dammed water caused a flood. Houses and infrastructure in the river valley were damaged.

Also, in 2016, there was a flood on the Akavreti river, which completely washed away the infrastructure of the restaurant "David" in the village of Oktomberi. The raging river in the Uchambi administrative unit took away the Kvafti bridge and cut off four villages from the central road: Tsablana, Samoleti, Moprineti, Laklaketi. The water also washed away the iron bridges of Gomikri,

Figure 6. River Safristskali valley 2021, (https://geologymaps.ge)

Okhorti and Tsiskvilighele in the village of Kviriauli. In the village of Kviriauli, the homestead of 10 families located on the shore of Uchambistskali was flooded.

A similar process took place in 1989 at river Skhalta. A flooded lake appeared. It was the result of blocking the valley by a landslide that came as a result of intense rains. (Fig. 7).

River On the left slope of Skhalta, the Salgoman mountain was hit by a landslide. The landslide came in two waves. During the first wave, the village of Tsablana, where 4 families lived, was completely buried. At the same time, the landslide engulfed the river Skhalta valley. It was followed by a second wave, during which the passengers who came to the rescue were killed. The second landslide further strengthened the submerged area of the river, buried the road that ran on the opposite slope. River above the dam. He buried the road that ran on the opposite (right) slope. The total volume of the crushed mass was 1.3 mln. m^3, the width along the river Skhalta - 450 m, the thickness to the crest of the dam is 45 m. Above the collapsed dam, the Skhalta River dammed up and a dammed up lake was formed. (Fig. 8) (Tsomaia et al., 2009).

Figure 7. Skhalta Dammed Lake and Skhalta River (1989 photo by V. Tsomaia)

If there was no place for its breakthrough and the related catastrophic flood, the channel was made. As a result, the flooded water went down, and a dangerous debris flow was avoided.

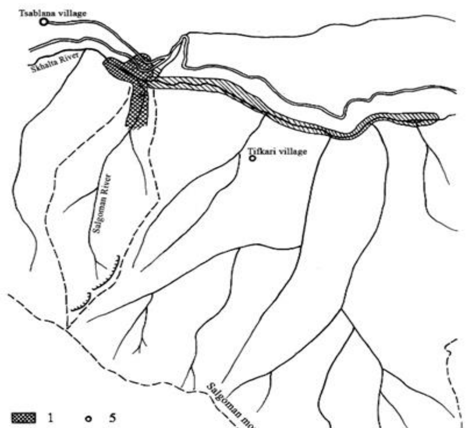


Figure 8. The rock-avalanched area of the Skhalta river and the flooded lake in the village of Tsablana (April 14, 1989). (1. A hollowed-out area; 2-a flooded lake; 3-a river; 4-a road; 5-a village; 6-a path; 7- rocky shores). (Tsomaia et al., 2009)

In the period of 2022 and 2023, such natural events took place several times, which caused significant damage to Batumi and its surroundings. The beginning of 2024 turned out to be tragic. On February 6, the avalanche took the life of one person who saved his family and could not get out of the avalanche cone himself. It is worth noting that during snowless winters, avalanches came here for years. Expedition groups are currently going to study avalanches with the participation of the author (Gorgijanidze et al., 2023a). The degree of avalanche hazard in Adjara is marked by particularly strong, less strong, medium and weak zones and the corresponding map is made. For 32 Avalanches of Khulo-Mlashe, Batumi-Akhaltsikhe Road, a schematic map of avalanche hazard, as well as for 161 avalanches of mountainous regions of Adjara and 32 avalanches, which converge on the automobile road, are computed morphometric and dynamic Indicators. (Salukvadze, 2020, Gorgijanidze et al., 2023b) The given schematic map shows the places of active avalanches in Adjara. (Fig. 9).

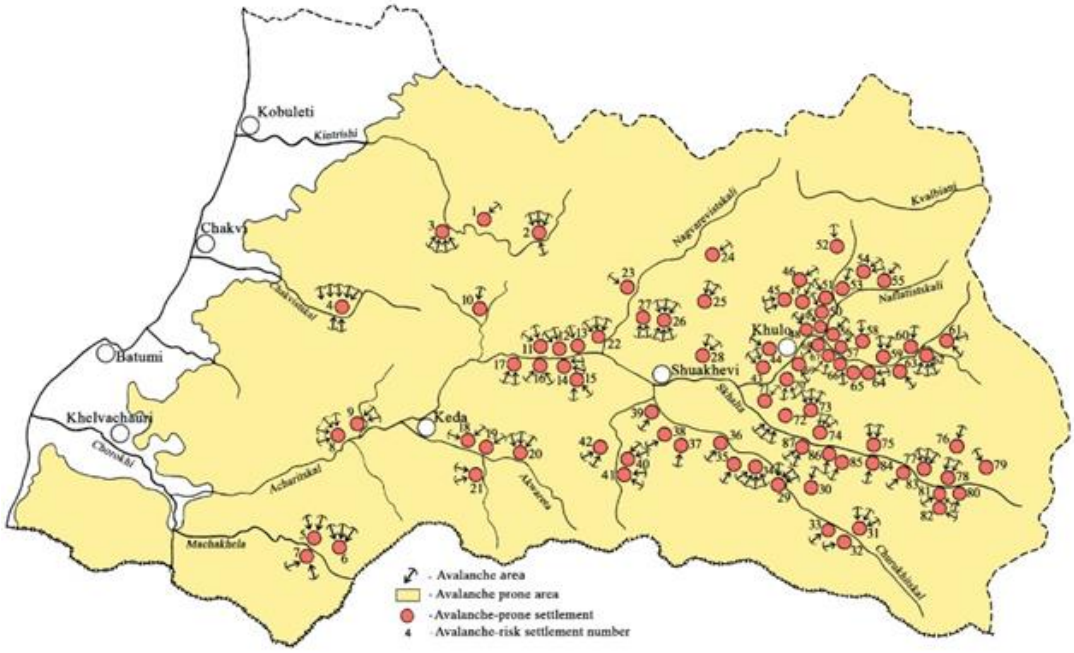


Figure 9. Avalanche settlements in the Adjara region (Salukvadze, 2020)

Methods

It should be noted that certain mechanisms and methodology have been developed by a group of authors, which consider the ways to prevent floods caused by the breakthrough of lakes dammed by river intrusion. It gives a certain forecast of what might happen to this or that blocked river. The methodology includes several stages.

1. First, the height of the impoundment dam (h) is measured, and the length (L) and width (B) of the embankment on the crest of the embankment dam are calculated for the height of the dam using a topographic map. Based on the received data, the volume of the impounded lake volume is determined (W) by the formula:

$$W = \frac{l \cdot B \cdot h}{k} \qquad (1)$$

where k is the coefficient to be calculated, it is considered equal to 3.

2. The expected length of flooding on the flooded area is determined, which begins with the overflow of water from the banks of the river;

3. The water consumption of the river and its tributaries above the catchment will be measured using known methods in hydrology. If we indicate the total water consumption of the river and its tributaries ΣQ, then the duration of filling the boiler (T) will be:

$$\mathrm{T} = \frac{W}{\sum Q} \qquad (2)$$

In this case, T is calculated in seconds, then converted to minutes, hours or days in the usual way.

4. As a result of the mass of water accumulated in the boiler, the dam can be breached. During dam failure, a trapezoidal shaped riverbed (like the well-known sluice in hydrometry) is produced. Therefore, the maximum flow of water is calculated by the well-known formula in hydraulics:

$$Q_m = 1{,}9 B \cdot h_1^{\frac{2}{3}} \qquad (3)$$

5. The maximum flow of water in the downstream reaches of the river undergoes a transformation due to the expansion of its water. In this regard, the use of the isochronous theory describing the flow gives us better results, according to which:

$$Q_{mn} = \frac{1}{l + l_n} \cdot Q_m \qquad (4)$$

where Q_m - is the maximum flow of flood water at the breakthrough location; (Tsomaia, 1985).

The maximum flow of water in the downstream reaches of the river transforms due to the expansion of its water. In this regard, the use of the isochronous theory describing the flow gives us a better result, according to which we will understand the magnitudes of the water expansion. These data provide the basis to further determine the duration of water filling of the dammed lake in the research areas and hydrographic parameters: maximum and average flood discharge, total duration, total volume of dammed water, and assessment of the stability of the dam. The main factor here is the water, which has a place to lie on the bottom of the mass that has been crushed as much as possible. (Tsomaia et al., 2009)

Results and Discussion

Methodology, statistical data and many theoretical materials reveal that the Adjara region is distinguished by its beauty and attractiveness, although it faces the threat of hydrological natural events almost every year. That is why this area is always being researched and studied, which allows to avoid these events. It should be noted that many prevention methods are improving at the modern stage. An early warning system has been developed which can completely or partially avert an impending threat to the region.

Avoiding floods is therefore one of the priorities in this region. In the conditions of abundant rainfall, the main thing is the correct management of the natural event, which will cause relatively less damage and, most importantly, will minimize casualties among the population. This is an important issue for the sustainable development of tourism in the Adjara region.

It should be noted here that in the background of climatic warming there are also objects that are threatened primarily by environmental degradation rather than natural hazards. Such are the lakes in the Ghorjomi valley formed by landslide blockage. Their breakthrough came with a small loss. Then 4 swampy lakes appeared in the area, three of which are on the way to swamps. However, this area is one of the attractive areas for tourists in mountainous Adjara. The existing lakes, which are hidden in the dense forest massifs, are the popular destinations for hikers. They are in danger of disappearing in the face of today's climate change, which is an ecological disaster.

Based on all the above, it is necessary and aimed to always observe hydrological natural events, which occur in the Adjara region almost every year. Knowledge of their mechanisms and statistical analysis of frequencies will allow us to properly manage catastrophic processes. Such a forecast will lead to positive results in the future depending on the seasons of the year. They carried out all the works that represent the riverbank stabilization, as well as the construction of protective dams, laying of canals and many other protective measures. This will avoid the casualties and losses in the region. Incorrect utilization of agricultural land, water erosion and other ecological problems should also be considered. Finally, it will have a positive impact on the sustainable development of tourism potential and tourism in the administrative unit of Adjara. This is most important for the economic stability of our country.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

All authors provided critical feedback and helped shape the research, analysis and manuscript.

ORCID iD

Sopio Gorgijanidze https://orcid.org/ 0000-0001-6574-8771
Mikheil Pipia https://orcid.org/0009-0006-3702-9554
Zaza Gulashvili https://orcid.org/0000-0002-9614-314X
Nazibrola Beglarashvili https://orcid.org/0000-0003-3298-7973

Natela Kobakhidze https://orcid.org/0000-0002-3780-872X

References

Geography of Georgia. (2000). Science Publishing House.

Geology Maps of Georgia. (n.d.). Danisparauli village – Sapristskali River. https://geologymaps.ge/ka/municipalities/Khulo/danisparauli-village-sapristskali-river-1

Georgian National Statistics Office. (n.d.). Tourism statistics. https://www.geostat.ge/ka/modules/categories/100/turizmis-statistika

Georgian Travel Guide. (n.d.). Georgia travel guide. https://georgiantravelguide.com

Georgian Travel Guide. (n.d.). Adjara. https://georgiantravelguide.com/en/adjara

Gorgijanidze, S., Saluqvadze, M., & Gorgodze, T. (2023). Avalanche danger and strategic purpose of passes and roads located in the border zone of Georgia. Samshoblo Publishing House.

Gorgijanidze, S., Beglarashvili, N., Pipia, M., Kobakhidze, N., & Jintcharadze, G. (2023). The spread of snow avalanches at transport junctions in the mountainous regions of Georgia. European Journal of Sustainable Development, 12(3).

Maruashvili, L. (1954). Landslides and avalanches in Georgia. Science and Technology, 2, 78–80.

Maruashvili, L. (1968). Physical geography of Georgia (Vol. 1, pp. 16–168). Tbilisi State University Press.

Maruashvili, L. I., Astakhov, N., Tskhovrebashvili, Sh. A., & Maisuradze, G. M. (1971). Caucasus: Geomorphology of Georgia. Metsniereba.

Saluqvadze, M. (2020). Avalanche hazard of Adjara mountainous regions. Institute of Hydrometeorology, Georgian Technical University.

Tsomaia, V. (1985). The youth of the “gray-haired” Caucasus Mountains. Science.

Tsomaia, V., Gachechiladze, G., Gorgijanidze, S., & Pkhakadze, M. (2009). Clogging floods and flows in Georgia. Institute of Hydrometeorology, Georgian Technical University.

YouTube. (n.d.). [Video]. https://www.youtube.com/watch?v=i3uf_1CWxxo

Multi-Temporal GIS Analysis of River Channel Migration Near a Pipeline Crossing: The Kura River, Azerbaijan

Aslan Babakhanov[1]

[1] Institute of Geography, Ministry of Science and Education, Republic of Azerbaijan

* Corresponding author: aslan.babakhanov@gmail.com

Georgian Geographical Journal, 2026, 6(1) 29-44

DOI:
https://journals.4science.ge/index.php/GGJ

Citation: Babakhanov, A. Multi-Temporal GIS Analysis of River Channel Migration Near a Pipeline Crossing: The Kura River, Azerbaijan. *Georgian Geographical Journal* 2026, 6(1), 29-44.
https://doi.org/10.52340/ggj.2026.06.01.05

Abstract

River crossings of linear infrastructure are often interpreted as fixed engineering locations, although the surrounding channel may undergo significant spatial reconfiguration over time. This study presents a multi-temporal GIS-based analysis of river channel migration near a pipeline crossing on the Kura River, Azerbaijan. The research focuses on the spatial interaction between channel migration, island development, flow redistribution, and the changing geomorphic context of the crossing corridor. Watercourse and exposed in-channel ground polygons were delineated from satellite imagery for 2001, 2007, 2009, 2010, 2012, and 2013 within a fixed geomorphic area of interest. A separate localized pipeline area of interest was used to assess spatial exposure indicators near the crossing corridor. Temporal overlay, area comparison, island fragmentation assessment, and proximity-based GIS interpretation were applied to evaluate morphodynamic change. The results indicate substantial reconfiguration of the active river corridor. The watercourse area increased from 16.41 ha in 2001 to 48.17 ha in 2010 and then decreased to 27.05 ha in 2013, while the exposed in-channel ground increased from 3.16 ha to 30.76 ha during the study period. The island fraction increased from 0.16 to 0.53, indicating a growing dominance of exposed alluvial surfaces within the mapped corridor. Pipeline-related spatial indicators also changed markedly, with the total pipeline length located within the 50 m near-bank zone increasing from 410 m in 2001 to 821 m in 2013. These changes show that the crossing should be considered part of a dynamic river interaction corridor rather than a static point. The proposed approach provides a reproducible GIS framework for spatial screening of riverine infrastructure exposure and for identifying crossing zones that may require field verification or closer monitoring. The findings represent GIS-based spatial indicators and should not be interpreted as direct measurements of pipeline exposure depth, scour, damage, or structural integrity.

Keywords: multi-temporal GIS; river corridor evolution; channel migration; alluvial island development; fluvial morphodynamics; spatial exposure indicators; geomorphic exposure screening; Kura River; Azerbaijan

Introduction

River channels are dynamic geomorphic systems whose spatial configuration may change considerably over time. In alluvial river environments, channel migration, bank erosion, sediment deposition, island formation, and flow redistribution can gradually reshape the active river corridor. Such behaviour is characteristic of actively adjusting alluvial river systems (Church, 2006; Fryirs & Brierley, 2013). These processes are especially important where rivers intersect linear infrastructure, because the crossing is often treated as a fixed engineering location, while the surrounding river morphology may continue to evolve. Studies of active meandering rivers show that channel instability is commonly spatially variable and may be expressed through localized erosion, deposition, widening, narrowing, or bend adjustment (Hooke, 2007).

Remote sensing and GIS provide an effective basis for detecting and interpreting such changes. Multi-temporal satellite images, aerial photographs, and vector-based spatial analysis allow researchers to compare watercourse footprints, identify erosion and deposition zones, map in-channel landforms, and quantify changes in river planform through time. These methods are widely used in fluvial geomorphology because they make it possible to reconstruct river corridor evolution where continuous field measurements are unavailable or limited (Gilvear & Bryant, 2016; Piégay et al., 2020). In this context, GIS analysis is not only a mapping tool, but also a methodological framework for interpreting spatial relationships between geomorphic processes and exposed elements of the landscape.

The problem becomes more specific near pipeline crossings. A buried pipeline crossing a river may remain fixed in its designed position, but the channel may migrate toward or away from it, split into branches, develop islands, or redistribute flow across the crossing corridor. Similar multi-thread and island-dominated configurations are widely documented in large alluvial river systems (Gurnell et al., 2001; Makaske, 2001). Therefore, the crossing should not be considered only as a static point or line. It may be more appropriately interpreted as a dynamic morphodynamic interaction corridor, where changes in river morphology influence the spatial context of infrastructure exposure. From a GIS and geoecological perspective, this does not imply direct assessment of pipeline damage, exposure depth, or structural integrity. Rather, it refers to spatial indicators that may help identify zones requiring closer monitoring or field verification.

The Kura River is the largest river system in Azerbaijan and represents an important fluvial corridor characterized by active lowland reaches, alluvial banks, meandering segments, and local channel reconfiguration. Spatial variability of such channel adjustment processes is typical for dynamically evolving river corridors (Hooke, 2007; Surian et al., 2009). In such conditions, pipeline crossings located near active river bends or island-forming zones may be affected by gradual changes in the spatial structure of the river corridor. This makes the Kura River a suitable case for applying multi-temporal GIS analysis to assess channel migration and corridor evolution change near critical infrastructure.

This study examines a pipeline crossing area on the Kura River using satellite image interpretation and GIS vector analysis for 2001, 2007, 2009, 2010, 2012, and 2013. Within a fixed geomorphic area of interest, watercourse polygons and exposed in-channel ground polygons were delineated and compared over time. A separate localized pipeline area of interest, hereafter referred to as the pipeline AOI, was used to assess spatial exposure indicators near the crossing corridor. This distinction is important because the broader geomorphic area describes river wide dynamics, while the pipeline AOI focuses on the local crossing environment.

In this methodological framework, the main dynamic processes described above were represented through measurable GIS indicators. Channel migration and bank adjustment were assessed by comparing annual watercourse footprints and their derived boundary proxies. Island development was evaluated through exposed in-channel ground polygons, island area, island fraction, and the number of island parts. Flow redistribution was interpreted from temporal changes in the spatial arrangement of watercourse and island polygons, including repeated transitions between water-covered and exposed states. The pipeline AOI was then used to relate these river-corridor changes to the crossing corridor through proximity, buffer-based, and intersection-based indicators. In this way, the GIS analysis reconstructs river corridor evolution not as a single mapped displacement, but as a sequence of planimetric changes in watercourse position, island structure, channel-thread distribution, and near-bank relationships.

The objective of the study is to develop a GIS-based interpretation of channel migration, island development, and river corridor reconfiguration near a pipeline crossing. The scientific contribution of the work lies in treating the crossing not as a fixed engineering point, but as part of a changing alluvial corridor. The proposed approach remains within GIS, fluvial geomorphology, geoecology, and spatial analysis. It is intended to support spatial monitoring and preliminary exposure screening, without replacing hydrodynamic modelling, geotechnical surveys, or engineering integrity assessment.

Methods and Materials

Study area

The study area shown in Figure 1 is located along the Kura River near Poylu, Azerbaijan. The analysed reach includes a river crossing corridor where the river channel interacts spatially with a pipeline alignment. The local planform is characterized by an active watercourse, an alluvial island,

and changes in channel-thread distribution observed in multi-temporal satellite imagery. A fixed geomorphic area of interest, hereafter referred to as the geomorphic AOI, was used for all mapped years. This methodological decision ensures that watercourse and island footprint areas are calculated within the same spatial frame, making temporal comparisons consistent. As a result, changes in watercourse area, island area, and island fraction can be interpreted as relative indicators of river corridor reconfiguration rather than as artefacts of changing analysis boundaries.

The study corridor represents an actively evolving river environment where local sediment accumulation, island development, and flow redistribution are visible in satellite imagery. The alluvial island is a key geomorphic element because it may divide the flow into separate channel threads and modify the position of active banks. Island-related redistribution of flow is recognized as an important component of large-river corridor evolution (Gurnell et al., 2001). As the island expands, fragments, or merges with smaller bars, it may contribute to narrowing of active flow paths and redistribution of hydraulic energy toward one or both banks.

The study area is therefore suitable for examining how channel migration and island development influence the spatial context of a pipeline crossing. In this study, the crossing is not treated as a fixed engineering point only, but as part of a dynamic river interaction corridor. This interpretation supports

Figure 2. Location of the study area along the Kura River near Poylu, Azerbaijan. Source: compiled by the author based on GIS data and satellite imagery

GIS-based monitoring of riverine infrastructure exposure while remaining distinct from direct engineering assessment of pipeline condition or structural integrity

Satellite Data and GIS Vector Preparation

Satellite imagery was used as the primary source for reconstructing the spatial configuration of the Kura River channel within the analysed reach. Multi-temporal image interpretation was carried out for six observation years: 2001, 2007, 2009, 2010, 2012, and 2013. These years were selected because they provide the most usable available historical sequence for identifying changes in the watercourse footprint, exposed in-channel ground, island development, and channel-thread distribution near the pipeline crossing corridor.

The satellite image sequence was compiled from available archival satellite sources for the selected observation years. The imagery included historical scenes accessible through Google Earth Pro where available, as well as archival Landsat-based imagery for earlier or otherwise unavailable years. The 2001 scene was not available in Google Earth Pro and was therefore treated as an archival satellite baseline. The 2007 scene had comparatively lower visual quality than the later images; consequently, its interpretation was carried out conservatively and with particular attention to persistent planform features.

Because the available historical scenes differ in image source, acquisition conditions, spatial resolution, illumination, and water-stage conditions, the study did not rely on automatic spectral classification. Instead, a consistent manual interpretation approach was applied to all observation years within the same geomorphic AOI. This ensured that the mapped watercourse and exposed in-channel ground polygons were compared within the same spatial frame, while uncertainty related to image quality was considered during visual interpretation.

The interpretation focused on two principal spatial classes: watercourse and exposed in-channel ground. The watercourse class represents the visible river water surface within the geomorphic AOI. The exposed in-channel ground class represents alluvial islands, bars, and island-like surfaces located within or immediately adjacent to the active river corridor. These mapped classes were selected because they directly represent the main planimetric elements through which channel migration, island development, and flow redistribution can be reconstructed from multi-temporal imagery.

The use of multi-temporal satellite imagery and GIS-based vector mapping is appropriate for this type of analysis because river planform changes, bankline shifts, in-channel landforms, and sedimentary features can often be detected through repeated image interpretation.

The satellite image interpretation scheme, including the role of each observation year and the mapped GIS outputs, is summarized in Table 1.

Table 2. Satellite image interpretation scheme and mapped GIS layers[3].

Observation Year	Image source/archive	Image quality / role	Mapped classes	GIS output
2001	Archival Landsat-based satellite imagery	Baseline scene; not available in Google Earth Pro	Watercourse; exposed in-channel ground	Annual polygon layers
2007	Historical satellite imagery/ Google Earth Pro where available	Lower visual quality; interpreted conservatively	Watercourse; exposed in-channel ground	Annual polygon layers
2009	Historical satellite imagery/ Google Earth Pro where available	Clearer intermediate scene	Watercourse; exposed in-channel ground	Annual polygon layers
2010	Historical satellite imagery/ Google Earth Pro where available	Clearer intermediate scene; maximum mapped watercourse extent	Watercourse; exposed in-channel ground	Annual polygon layers
2012	Historical satellite imagery/ Google Earth Pro where available	Later-stage corridor configuration	Watercourse; exposed in-channel ground	Annual polygon layers
2013	Historical satellite imagery/ Google Earth Pro where available	Final mapped corridor configuration	Watercourse; exposed in-channel ground	Annual polygon layers

Remote sensing and aerial image analysis are widely used in fluvial geomorphology for mapping landforms and measuring temporal changes in river systems (Gilvear & Bryant, 2016). More recent studies also emphasize the role of remote sensing in monitoring river corridor conditions and interpreting fluvial processes at different spatial and temporal scales (Piégay et al., 2020).

For each analysed year, the visible boundaries of the watercourse and exposed in-channel ground were manually digitized as polygon layers. Manual digitization was preferred because the analysed corridor contains narrow channel branches, irregular island margins, shallow-water zones, and transitional wet surfaces that may be difficult to classify reliably using automatic threshold-based methods alone. The interpretation was based on visual criteria such as tone, colour contrast, texture, shape, continuity of water surfaces, and the spatial relationship between the river channel and exposed sedimentary surfaces.

All annual vector layers were prepared within the same geomorphic AOI. This ensured that watercourse area, island area, and island fraction were calculated within an identical spatial frame for all years. The use of a fixed boundary is important because it prevents changes in calculated areas from being caused by differences in map extent. Therefore, temporal differences in polygon areas can be interpreted as indicators of actual river corridor reconfiguration within the selected reach.

The vector preparation workflow included several steps. First, satellite images for each year were reviewed and visually compared. Second, watercourse and exposed ground polygons were digitized

[3] *Note: The table summarizes the interpretation scheme used in the study. Image availability and quality varied between observation years. The 2001 scene was used as an archival baseline, while the 2007 scene was retained despite lower visual quality because it provided an intermediate temporal reference between 2001 and 2009. All mapped years were processed using the same fixed geomorphic boundary and the same visual interpretation criteria.*

for each observation year. Third, all polygon layers were clipped to the geomorphic AOI. Fourth, topology checks were performed to reduce overlaps, gaps, and geometry errors. Fifth, area values were calculated for each polygon class. Finally, the annual layers were organized into a multi-temporal GIS database for overlay analysis and comparison.

A separate pipeline AOI was also prepared. Unlike the broader geomorphic AOI, which was used to analyse the general river reach, the pipeline AOI was used to assess spatial indicators near the crossing corridor. This distinction allows the study to separate reach-scale channel behaviour from local exposure-related indicators around the pipeline alignment. The pipeline layer was used only as a spatial reference for GIS-based interpretation and was not used for structural or mechanical pipeline assessment.

All spatial data were processed in WGS 84 UTM zone 38N. Area calculations were performed in projected coordinates to avoid distortions associated with geographic coordinate systems. The final GIS dataset consisted of annual watercourse polygons, annual exposed ground polygons, the geomorphic AOI, the pipeline AOI, and the pipeline alignment. These layers formed the basis for subsequent calculations of watercourse area, island area, island fraction, island fragmentation, and exposure-related spatial indicators.

Area of Interest Definition

Two spatial areas of interest were used in the study. The geomorphic AOI covers the analysed river reach and was used for calculating watercourse and island footprint dynamics. This boundary was kept unchanged for all observation years to ensure that temporal changes were compared within the same spatial frame.

The pipeline AOI represents a localized corridor around the pipeline crossing. It was used only for assessing spatial exposure indicators near the crossing zone, such as the relationship between the pipeline alignment, active watercourse, and nearby in-channel landforms.

The separation of these two areas is methodologically important. The geomorphic AOI reflects reach scale river corridor changes, whereas the pipeline AOI focuses on local interaction between channel migration and the crossing corridor. This distinction prevents mixing general fluvial trends with infrastructure related spatial indicators.

GIS Metrics and Spatial Analysis

GIS metrics were calculated to quantify the temporal reconfiguration of the river corridor and to assess the changing spatial relationship between the active channel, alluvial island surfaces, and the pipeline crossing. The analysis was based on polygon footprints of the watercourse and exposed in-channel ground prepared for 2001, 2007, 2009, 2010, 2012, and 2013. The methodological logic follows a multi-temporal planform comparison approach, in which remotely sensed river features are converted into comparable vector layers and then analyzed through overlay, area calculation, boundary extraction, and proximity measurement. Such approaches are commonly used in fluvial geomorphology for detecting channel migration, mapping river landforms, and measuring temporal changes in river corridors (Gilvear & Bryant, 2016; Piégay et al., 2020).

The analysis was carried out in several consecutive steps. First, watercourse and exposed in-channel ground polygons were prepared for each observation year and clipped to the same geomorphic AOI. Second, area metrics were calculated to describe changes in the watercourse footprint, island footprint, island fraction, and island structure. Third, temporal overlay and geometric difference operations were used to identify zones where the mapped corridor changed from water to exposed ground, or from exposed ground to water. Fourth, the localized pipeline AOI was used to compare the annual river configuration with the pipeline alignment. At this stage, the analysis included buffer measurements near the mapped bank proxy, intersections between the pipeline and the watercourse or island polygons, and the distance from the middle part of the mapped crossing segment to the nearest bank proxy. This workflow connects the interpreted satellite features with the reconstruction of river corridor evolution and with the assessment of spatial exposure indicators near the crossing.

The metrics used in this study are based on standard GIS geometric operations, including polygon area calculation, overlay analysis, buffering, boundary extraction, geometric difference, and proximity measurement. Their scientific contribution lies not in the development of new mathematical formulations, but in the integration of these spatial indicators into a multi-temporal river corridor interpretation framework for analyzing river corridor evolution near a pipeline crossing. In this framework, area metrics describe the changing composition of the active corridor, overlay metrics describe the spatial redistribution of water and exposed ground, and proximity metrics describe the changing relationship between the river corridor and the pipeline alignment. Comparable GIS-based approaches are commonly applied in river corridor analysis and geomorphic interpretation studies (Belletti et al., 2017).

For each observation year (t), two main polygon classes were used. The first class, W(t), represents the watercourse footprint, that is, the visible river water body within the geomorphic AOI. The second class, I(t), represents exposed in-channel ground, interpreted in this study as alluvial island or island-like surfaces inside the active river corridor. All area values were calculated in the projected coordinate system with metric units and then converted to hectares.

The watercourse area was defined as:

$$A_w(t) = \text{Area}[W(t)]$$

where $A_u(t)$ is the watercourse area in year t.

The island area was defined as:

$$A_i(t) = \text{Area}[I(t)]$$

where $A_i(t)$ is the exposed in-channel ground or island area in year t.

The combined mapped active footprint was calculated as:

$$A_t(t) = A_w(t) + A_i(t)$$

This combined footprint does not represent the full floodplain or the complete channel belt. It represents only the mapped watercourse and island/ground surfaces within the geomorphic AOI. It is therefore used as a local GIS indicator of river corridor configuration rather than as a hydrological measure of channel capacity.

To normalize island development relative to the mapped river corridor, the island fraction was calculated as:

$$F_i(t) = \frac{A_i(t)}{A_w(t) + A_i(t)}$$

where $F_i(t)$ expresses the proportion of exposed in-channel ground within the combined watercourse-island footprint. Higher values of $F_i(t)$ indicate a larger relative dominance of island surfaces within the crossing corridor. This metric is useful because absolute island area alone may be influenced by changes in the total mapped watercourse extent, while the fraction provides a normalized indicator of island dominance.

Temporal changes in watercourse and island areas were calculated between consecutive observation years or selected epochs. The absolute change in watercourse area was expressed as:

$$\Delta A_w(t_1, t_2) = A_w(t_2) - A_w(t_1)$$

The absolute change in island area was expressed as:

$$\Delta A_i(t_1, t_2) = A_i(t_2) - A_i(t_1)$$

Relative island growth was calculated as:

$$G_i(t_1, t_2) = \frac{A_i(t_2) - A_i(t_1)}{A_i(t_1)} \times 100$$

where $G_i(t_1, t_2)$ is the percentage change in island area between two epochs. The same logic can be applied to the watercourse footprint when relative watercourse change is required:

$$G_w(t_1, t_2) = \frac{A_w(t_2) - A_w(t_1)}{A_w(t_1)} \times 100$$

Island structure was also described using the number of island parts:

$$N_i(t) = \text{count}\left[I_{\text{parts}}(t)\right]$$

where $N_i(t)$ is the number of polygon parts after multipart decomposition. This metric was used as a descriptive indicator of island fragmentation or coalescence. In this study, changes in $N_i(t)$ are not interpreted as direct evidence of a single geomorphic process. Rather, they indicate changes in the mapped spatial structure of exposed in-channel ground. Such changes may reflect actual island fragmentation, merging of smaller bars, differences in inundation level, or image interpretation uncertainty.

For bank-related analysis, a bank proxy was derived from the boundary of the watercourse polygon:

$$B(t) = \partial W(t)$$

where B(t) is the GIS-derived watercourse boundary for year t, and ∂W(t) denotes the polygon boundary of the mapped watercourse footprint. This boundary is not a surveyed engineering bankline. It represents the planimetric water edge extracted from the annual GIS footprint. Therefore, all distance and proximity indicators based on B(t) are interpreted as GIS-based spatial indicators, not as field-surveyed bank positions or measurements of pipeline burial depth.

Pipeline-related metrics were calculated within the localized pipeline AOI. This AOI was kept separate from the broader geomorphic AOI because pipeline exposure indicators must represent the local crossing corridor rather than the entire river reach. The use of a focused crossing corridor is consistent with the broader concept that channel migration and river corridor change should be analyzed as spatial zones rather than as isolated points (Rapp & Abbe, 2003). In this study, two parallel pipeline polylines were processed and denoted as P_1 and P_2. For general notation, P_p refers to pipeline p, where $p \in \{1, 2\}$.

Near-bank exposure length was calculated using 50 m and 100 m buffers around the bank proxy. For each pipeline P_p, the length located within 50 m of the bank proxy was calculated as:

$$L_{50}^{(p)}(t) = \mathrm{Length}\left[P_p \cap \mathrm{Buffer}(B(t), 50)\right]$$

Similarly, the length located within 100 m of the bank proxy was calculated as:

$$L_{100}^{(p)}(t) = \mathrm{Length}\left[P_p \cap \mathrm{Buffer}(B(t), 100)\right]$$

For the two parallel pipelines, total near-bank exposure lengths were calculated as:

$$L_{50}^{(\Sigma)}(t) = \sum_{p=1}^{2} L_{50}^{(p)}(t)$$

$$L_{100}^{(\Sigma)}(t) = \sum_{p=1}^{2} L_{100}^{(p)}(t)$$

These indicators show how much of the pipeline alignment is located near the mapped watercourse boundary in each epoch. They do not indicate actual physical exposure of the pipeline. Instead, they identify the length of pipeline alignment located within predefined near-bank GIS zones.

Additional crossing-configuration indicators were calculated by intersecting the pipeline polylines with the watercourse and island footprints. Pipeline length intersecting the watercourse footprint was calculated as:

$$L_{w}^{(p)}(t) = \mathrm{Length}\left[P_p \cap W(t)\right]$$

Pipeline length intersecting the island footprint was calculated as:

$$L_{i}^{(p)}(t) = \mathrm{Length}\left[P_p \cap I(t)\right]$$

For both pipelines combined, the total watercourse-crossing and island-crossing lengths were calculated as:

$$L_{w}^{(\Sigma)}(t) = \sum_{p=1}^{2} L_{w}^{(p)}(t)$$

$$L_{i}^{(\Sigma)}(t) = \sum_{p=1}^{2} L_{i}^{(p)}(t)$$

These metrics are useful for describing whether the crossing corridor is dominated by open water or by exposed in-channel ground in plan view. A decrease in $L_u^{(\Sigma)}(t)$ together with an increase in $L_i^{(\Sigma)}(t)$ may indicate that the island footprint occupies a larger part of the crossing corridor. However, this is still a planimetric GIS interpretation and should not be interpreted as direct evidence of changes in pipeline cover, scour depth, or structural condition.

A simple minimum distance from the pipeline to the bank proxy may be misleading at a river crossing because the pipeline necessarily intersects the river corridor in plan view. Therefore, a crossing-safe midpoint distance was used. First, the pipeline segment intersecting the watercourse footprint was defined as:

$$S_w^{(p)}(t) \ = \ P_p \ \cap \ W(t)$$

The midpoint of this underwater segment was then calculated as:

$$m_w^{(p)}(t) \ = \ \text{Midpoint}\left[S_w^{(p)}(t)\right]$$

The distance from this midpoint to the bank proxy was calculated as:

$$d_{mid}^{(p)}(t) \ = \ \text{Distance}\left[m_w^{(p)}(t), B(t)\right]$$

For the two parallel pipelines, the minimum midpoint-to-bank distance was reported as:

$$d_{\text{mid,min}}(t) \ = \ \min\left[d_{mid}^{(1)}(t), d_{mid}^{(2)}(t)\right]$$

This metric describes how close the center of the mapped underwater crossing segment is to the nearest bank proxy. A decrease of $d_{mid,min}(t)$ in this distance may indicate that the active channel configuration is tightening around the pipeline crossing corridor. It should not be interpreted as a direct measurement of pipeline exposure depth or engineering risk.

Where polygon overlays between two epochs were required, watercourse expansion and contraction areas were calculated using geometric difference operations. Water expansion between two epochs was defined as:

$$E_w(t_1, t_2) \ = \ \text{Area}[W(t_2) \ - \ W(t_1)]$$

Water contraction was defined as:

$$C_w(t_1, t_2) \ = \ \text{Area}[W(t_1) \ - \ W(t_2)]$$

These overlay-based indicators can be interpreted as planform water-occupation change. They may reflect erosion, accretion, inundation differences, island emergence, vegetation stabilization, or water-stage effects. For this reason, the terms “water expansion” and “water contraction” are preferred in the metric description, while geomorphic interpretation is provided cautiously in the Results and Discussion sections.

All calculated metrics were organized into annual summary tables. The principal output indicators include watercourse area, island area, island fraction, number of island parts, total pipeline length within the 50 m and 100 m near-bank zones, pipeline length intersecting the watercourse and island footprints, and the minimum midpoint-to-bank distance.

Together, these indicators describe the evolution of the watercourse-island configuration and the changing spatial relationship between the river corridor and the pipeline crossing. The methodology is intended for GIS-based exposure screening and alluvial corridor monitoring. It does not replace hydrodynamic modeling, bathymetric survey, geotechnical investigation, or pipeline structural integrity assessment.

Results

Watercourse and Island Footprint Dynamics

The multi-temporal GIS analysis shows that the analyzed river corridor of the Kura River underwent substantial spatial reconfiguration between 2001 and 2013. Changes were observed in the geometry of the active watercourse, the extent of exposed in-channel ground, the structure of alluvial island surfaces, and the distribution of channel threads within the fixed geomorphic AOI.

The calculated metrics demonstrate that both the watercourse footprint and the island footprint changed considerably through time (Table 2). The observed variations indicate that the river corridor remained morphodynamically active during the analyzed period rather than maintaining a stable planform configuration. The watercourse area increased from 16.41 ha in 2001 to 48.17 ha in 2010, after which it decreased to 23.27 ha in 2012 and 27.05 ha in 2013. In contrast, the exposed in-channel ground increased more continuously, from 3.16 ha in 2001 to 30.76 ha in 2013. The island fraction also increased from 0.16 to 0.53 during the study period. These values show that the later corridor configuration was characterized not only by changes in water extent, but also by a much stronger presence of exposed alluvial surfaces.

Table 3. Multi-temporal watercourse and island metrics within the geomorphic AOI.

Year	Watercourse area (ha)	Island area (ha)	Island fraction	Island parts
2001	16.41	3.16	0.16	1
2007	24.43	4.37	0.15	1
2009	45.17	12.06	0.21	3
2010	48.17	8.10	0.14	6
2012	23.27	29.18	0.55	6
2013	27.05	30.76	0.53	5

The earliest analyzed epoch, 2001, represents a comparatively simple corridor configuration, with one mapped island part and a low island fraction. By 2007, the corridor already showed signs of reorganization, including an increase in both watercourse areas and exposed in-channel ground. Because the 2007 image has lower visual quality than the later scenes, this epoch should be interpreted mainly as an intermediate reference between the 2001 baseline and the clearer 2009–2013 sequence.

The period between 2007 and 2010 corresponds to the phase of maximum mapped watercourse expansion, with watercourse area increasing from 24.43 ha in 2007 to 48.17 ha in 2010. Satellite imagery and GIS overlays indicate changes in channel-thread distribution, local reorganization of island margins, and increasing complexity of the exposed in-channel ground structure. In several sections of the corridor, the active watercourse became subdivided into separate branches around the developing island system. Such multi-thread channel configurations are commonly associated with active adjustment processes in alluvial river systems (Hicks et al., 2008). This process produced a more fragmented planform pattern and altered the spatial distribution of active flow paths.

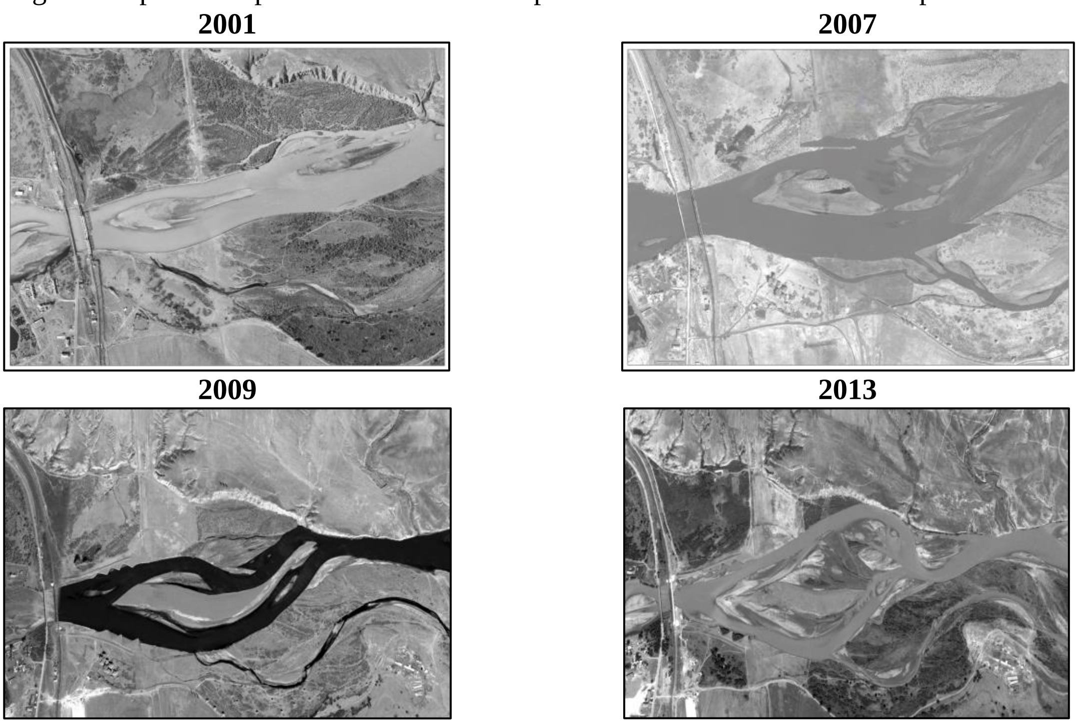


Figure 2. Selected satellite scenes illustrating temporal evolution of the Kura River crossing corridor between 2001 and 2013.

By 2012 and 2013, the role of exposed in-channel ground became dominant within the mapped corridor: island area reached 29.18 ha in 2012 and 30.76 ha in 2013, while island fraction increased to 0.55 and 0.53, respectively. The island footprint occupied a larger proportion of the geomorphic AOI, while several active water branches became narrower or more spatially constrained. The increase in island fraction values indicates that exposed alluvial surfaces became progressively more dominant within the mapped river corridor during the later observation years. At the same time, multipart island structure and local coalescence of smaller bar-like forms suggest continuing fluvial adjustment rather than stabilization of a single permanent island geometry, which is consistent with observations reported for actively evolving alluvial corridors (Ashmore, 1982; Makaske, 2001).

The temporal evolution of the river corridor is illustrated in Figure 2, which presents the multi-temporal satellite sequence for the analyzed years.

Visual interpretation of the annual satellite scenes demonstrates that changes in the study reach were not limited to simple lateral migration of a single channel thread. Instead, the river corridor experienced spatial redistribution of water flow around evolving island surfaces, localized narrowing and widening of active branches, and repeated modification of exposed sedimentary forms. These processes indicate a dynamically adjusting alluvial corridor in which the position and configuration of active water pathways changed through time.

To support comparison between epochs, annual watercourse and island polygons were overlaid within the fixed geomorphic AOI (Fig. 3). The overlay analysis highlights both persistent and transitional spatial zones within the river corridor. Some parts of the active channel remained relatively stable throughout the study period, whereas other sections experienced repeated alternation between water-covered and exposed states.

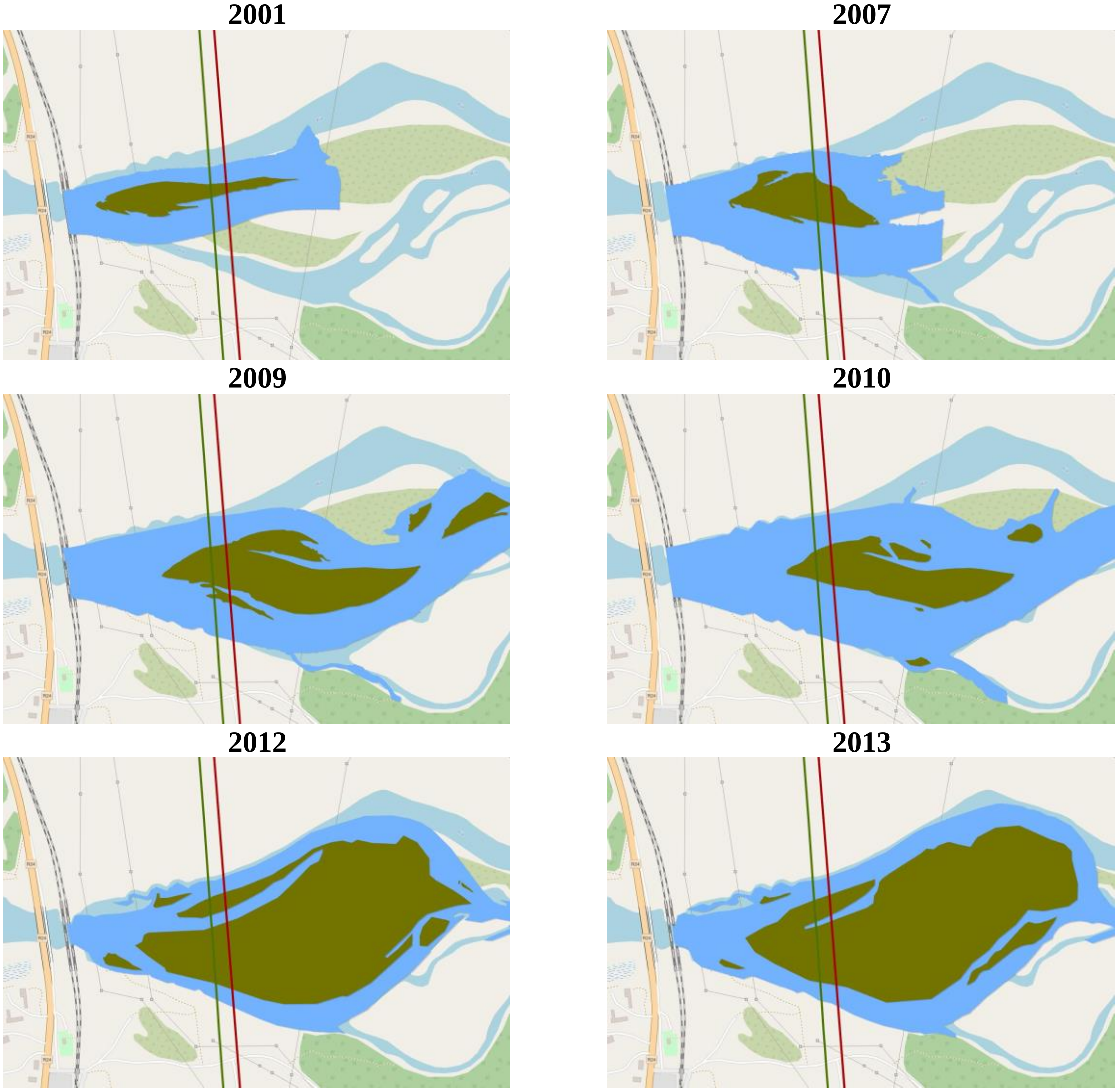


Figure 3. Multi-temporal GIS overlays of annual watercourse and island polygons illustrate spatial reconfiguration of the river corridor within the geomorphic AOI.

The overlay results suggest that the analyzed reach should be interpreted as a morphodynamically active corridor rather than as a geometrically stable river crossing. Changes in island extent, channel-thread configuration, and watercourse distribution demonstrate that the spatial structure of the river corridor evolved continuously during the observed period. These changes are important because they influence the local geomorphic context in which the pipeline crossing is located.

The observed dynamics do not directly indicate erosion hazard, bank instability, or engineering exposure of the pipeline. Instead, they represent GIS-based spatial indicators of river corridor reconfiguration. Their significance lies in demonstrating that the crossing environment changed measurably through time and that the active river corridor cannot be treated as a static spatial feature.

Multi-Temporal Channel Reconfiguration

The overlay analysis indicates that the analyzed corridor experienced progressive channel adjustment throughout the observation period. The spatial relationship between the active channel branches and the central island area changed repeatedly between epochs, producing a dynamically reconfigured river corridor rather than a stable planform geometry.

One of the most visible tendencies is the redistribution of flow around the developing island system. In the earlier epochs, the active watercourse occupied a comparatively broader corridor with less dominant exposed in-channel ground. During later epochs, the island system became more spatially pronounced and locally constrained the geometry of active channel branches. This process contributed to narrowing several water pathways and to increasing asymmetry between channel threads.

The temporal overlays also show that some sectors of the river corridor remained comparatively persistent, while other sectors underwent repeated transitions between water-covered and exposed states. Such transitions are important because they indicate spatial instability within the active corridor rather than simple lateral migration of a single riverbank.

Changes in multipart island structure suggest continuing reorganization of sedimentary surfaces within the river corridor. Such reorganization processes are typical of sediment redistribution within multi-thread alluvial systems (Church, 2006; Surian et al., 2009). In several epochs, smaller exposed areas appear to merge into larger island forms, whereas in other periods the exposed surfaces become more fragmented. These patterns are consistent with active alluvial adjustment influenced by flow redistribution and local sediment accumulation.

The results demonstrate that the river crossing corridor cannot be interpreted as geomorphically static. Instead, the spatial organization of the active watercourse evolved continuously during the study period through changing relationships between water-covered and exposed surfaces. This river adjustment behavior is particularly important in the vicinity of the pipeline crossing because it modifies the spatial context in which the crossing is located.

The identified reconfiguration patterns should be interpreted as GIS-based indicators of river corridor evolution rather than as direct measurements of erosion intensity, bank failure, or engineering exposure. Nevertheless, the observed planform adjustments demonstrate that the crossing environment remained dynamically active during the study period.

Pipeline Corridor Spatial Indicators

The calculated pipeline corridor indicators demonstrate that the spatial relationship between the active river corridor and the pipeline crossing changed substantially during the observation period. In particular, the results indicate increasing interaction between the evolving channel configuration and the localized crossing corridor during the later epochs (Table 3).

Table 4. Pipeline corridor spatial indicators for the inspected epochs[4]

Year	$\boldsymbol{d}_{\mathbf{mid,min}}$ **(m)**	$\boldsymbol{L}_{\mathbf{50}}^{(\boldsymbol{\Sigma})}$ **(m)**	$\boldsymbol{L}_{\mathbf{100}}^{(\boldsymbol{\Sigma})}$ **(m)**	$\boldsymbol{L}_{\mathbf{w}}^{(\boldsymbol{\Sigma})}$ **(m)**	$\boldsymbol{L}_{\mathbf{i}}^{(\boldsymbol{\Sigma})}$ **(m)**
2001	93.6	410	806	398	75
2007	169.8	417	827	743	269
2009	161.1	414	839	760	306
2010	165.3	415	837	768	218
2012	24.5	814	1200	280	488

[4] Note: $\boldsymbol{d}_{\mathbf{mid,min}}$ *is the minimum midpoint-to-bank distance for the mapped underwater crossing segment.* $\boldsymbol{L}_{50}^{(\boldsymbol{\Sigma})}$ *and* $\boldsymbol{L}_{100}^{(\boldsymbol{\Sigma})}$ *are the total lengths of the two pipeline polylines located within 50 m and 100 m of the mapped bank proxy, respectively.* $\boldsymbol{L}_{\mathbf{w}}^{(\boldsymbol{\Sigma})}$ *is the total pipeline length intersecting the mapped watercourse footprint.* $\boldsymbol{L}_{i}^{(\boldsymbol{\Sigma})}$ *is the total pipeline length intersecting the exposed in-channel ground footprint. All values are planimetric GIS indicators and do not represent pipeline burial depth, scour depth, or structural condition.*

2013	27.8	821	1201	272	500

The temporal behaviour of the principal indicators is summarized in Figure 4.

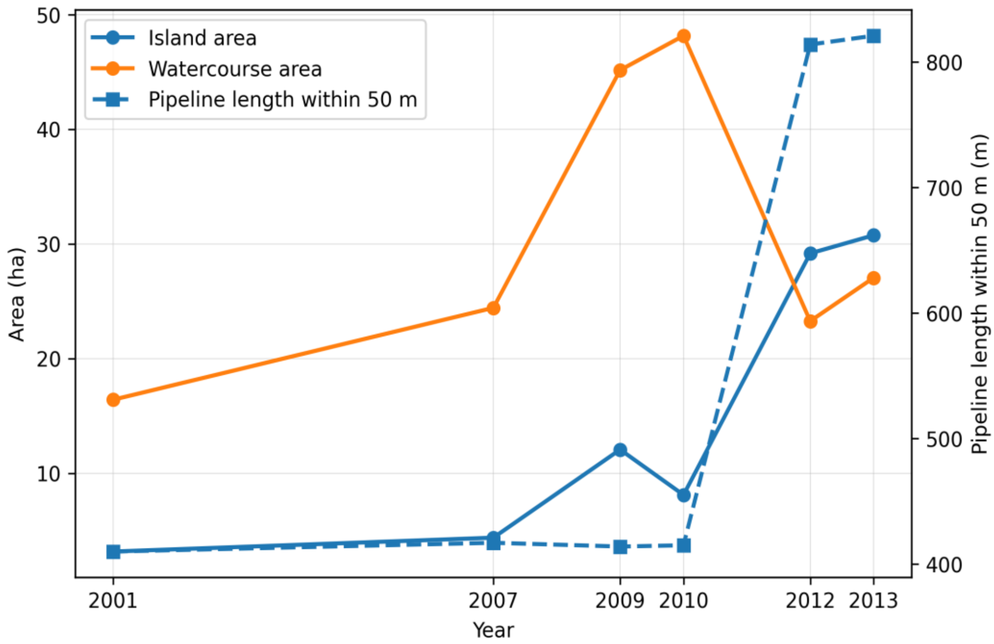


Figure 4. Temporal evolution of watercourse area, island area, and total pipeline length located within the 50 m near-bank zone.

The watercourse area increased from 2001 to 2010, reaching its maximum extent during 2010. This phase corresponds to a comparatively broader active river corridor with expanded water-covered surfaces and active channel redistribution around the island system. During the same interval, the total pipeline length located within the 50 m near-bank zone remained relatively stable, indicating that although the watercourse expanded, the immediate proximity relationship between the active bank proxy and the pipeline alignment changed only moderately.

A different tendency became visible after 2010. The watercourse footprint decreased considerably during 2012–2013, while the island area increased sharply and became one of the dominant components of the mapped corridor. This transition reflects progressive development and spatial consolidation of exposed in-channel ground within the crossing reach.

At the same time, the total pipeline length located within the 50 m near-bank zone increased abruptly from 415 m in 2010 to 814 m in 2012 and remained high at 821 m in 2013. The 100 m near-bank indicator shows the same shift, increasing from 837 m in 2010 to 1200 m in 2012 and 1201 m in 2013. Compared with the relatively stable values observed between 2001 and 2010, the later epochs indicate a substantial expansion of near-bank interaction zones along the pipeline corridor. This behavior suggests that the active channel configuration became more spatially constrained around the crossing area during the later stages of corridor evolution.

The combined interpretation of watercourse areas, island growth, and near-bank pipeline metrics indicates that the channel evolution of the corridor was not controlled only by simple widening or narrowing of the river. Instead, the corridor experienced redistribution of active flow around increasingly developed island surfaces. As the island system expanded, several active channel branches became narrower and locally shifted toward sectors of the pipeline alignment, increasing the proportion of the corridor located within predefined near-bank buffer zones.

The results therefore suggest a progressive tightening of the active river corridor around the crossing area during the later epochs. This interpretation is also consistent with the reduction of the midpoint-to-bank distance from 165.3 m in 2010 to 24.5 m in 2012 and 27.8 m in 2013. Together with the increasing dominance of exposed in-channel ground within the mapped corridor, this indicates that the crossing area became spatially more constrained in the later part of the analyzed sequence.

These indicators should be interpreted as GIS-based spatial metrics derived from planimetric relationships between annual river footprints, mapped bank proxies, and the pipeline alignment. They do not represent direct measurements of bank erosion rate, scour depth, pipeline exposure, or structural condition. Nevertheless, the temporal trends demonstrate that the spatial context of the crossing changed substantially during the study period and that the interaction between the river corridor and the pipeline alignment became progressively more localized and asymmetrical.

Morphodynamic Interpretation of the Crossing Corridor

The combined results of the multi-temporal GIS analysis indicate that the investigated reach evolved as a dynamically adjusting river corridor throughout the observation period.

The temporal relationship between the active watercourse, exposed in-channel ground, and the pipeline alignment demonstrates that the crossing environment cannot be interpreted as spatially static.

One of the principal tendencies observed during the study period is the progressive increase in the geomorphic importance of the central island system. In the earlier epochs, the active watercourse occupied a comparatively broader and more continuous corridor. During later epochs, however, the exposed in-channel ground expanded substantially and became increasingly dominant within the mapped corridor. This transition was accompanied by redistribution of flow around the island complex and by local narrowing of several active channel branches.

The observed changes suggest that the morphodynamic behaviour of the corridor was controlled not only by lateral migration of a single channel thread, but also by repeated reorganization of flow pathways around evolving sedimentary surfaces. Comparable adjustment patterns have been described in studies of active alluvial river systems and channel-thread redistribution (Ashmore, 1982; Fryirs & Brierley, 2013). As the island system expanded and locally coalesced, the active channel geometry became more asymmetric and spatially constrained. This tendency is reflected both in the increasing island fraction values and in the growth of near-bank pipeline indicators during the later observation years.

The relationship between the river corridor and the pipeline crossing also changed progressively through time. During the earlier epochs, the crossing corridor remained comparatively distant from the most spatially constrained parts of the active channel system. In contrast, the later epochs indicate increasing localization of active water pathways near segments of the pipeline alignment. The sharp increase in the total pipeline length located within the 50 m near-bank zone after 2010 suggests that the active fluvial interaction corridor became more concentrated around parts of the crossing area.

At the same time, the reduction of midpoint-to-bank distance indicators implies that the spatial configuration of the active channel evolved toward a tighter interaction with the crossing corridor. This tendency does not necessarily indicate direct engineering exposure to the pipeline. Rather, it reflects increasing spatial proximity between the active channel geometry and the pipeline alignment within the planimetric GIS framework used in this study.

The morphodynamic interpretation is further supported by the temporal overlay analysis, which shows repeated alternation between water-covered and exposed states in several sectors of the corridor. Such transitions indicate persistent instability of the local channel configuration and suggest continuing sediment redistribution within the reach. The coexistence of expanding island surfaces, narrowing active branches, and shifting near-bank zones indicates an actively reorganizing alluvial environment rather than a stable river crossing geometry.

Overall, the results support the interpretation of the crossing area as a dynamic river crossing corridor. In this context, the pipeline crossing should not be viewed solely as a fixed engineering point intersecting a stable river channel. Instead, it is located within a spatially evolving fluvial system where channel-thread redistribution, island development, and changing bank proximity continuously modify the geomorphic context of the crossing. The identified patterns therefore provide a GIS-based basis for long-term spatial monitoring of river corridor evolution near critical linear infrastructure.

Discussion

The results demonstrate that the investigated area of the Kura River functioned as a dynamically evolving river corridor throughout the study period. The temporal sequence of satellite imagery and GIS overlays indicates that the river corridor was characterized not only by lateral adjustment of the active watercourse, but also by progressive reorganization of flow pathways around expanding and restructuring island surfaces. Such behaviour is typical of active alluvial systems in which sediment accumulation, channel-thread redistribution, and alternating water-covered and exposed states continuously modify the spatial structure of the river corridor. These processes are widely recognized as characteristic features of actively adjusting fluvial systems (Church, 2006; Fryirs & Brierley, 2013).

One of the most important tendencies identified in the study is the increasing geomorphic role of exposed in-channel ground during the later observation years. The combined interpretation of island growth, increasing island fraction, narrowing active branches, and rising near-bank pipeline indicators suggests that the river corridor evolved toward a more spatially constrained configuration near the crossing zone. Similar tendencies toward localized corridor adjustment and island-controlled flow redistribution have been documented in large alluvial rivers (Gurnell et al., 2001; Surian et al., 2009). In this context, the pipeline crossing should not be interpreted only as a fixed engineering location intersecting a stable river channel. Instead, it is more appropriately viewed as part of a dynamic evolving fluvial corridor in which the geometry of active water pathways changes through time.

In this study, long-term stability of the crossing corridor is interpreted in spatial and geomorphic terms rather than in direct engineering terms. A relatively stable crossing corridor would be expected to show limited change in watercourse position, low variation in exposed in-channel ground, limited alternation between water-covered and exposed states, and relatively stable near-bank pipeline indicators. In contrast, the analysed reach shows a different pattern. The increase in island area and island fraction, the narrowing and redistribution of active channel branches, the abrupt rise in pipeline length located within the 50 m and 100 m near-bank zones, and the reduction of midpoint-to-bank distance all indicate that the crossing corridor became spatially less stable during the later observation years. Therefore, the potential risk identified here should be understood as geomorphic exposure potential: a higher need for field verification, repeated monitoring, and possible engineering review, not as direct evidence of pipeline damage or loss of cover.

The GIS-based indicators used in this study therefore provide a spatial framework for ranking or prioritizing crossing zones where river corridor evolution may alter the local exposure context of buried infrastructure. Spatial understanding of river corridor adjustment is increasingly recognized as important for long-term environmental and infrastructure management in dynamic fluvial systems (Lane, 2017). At the same time, the results must be interpreted cautiously. The calculated metrics represent planimetric GIS relationships derived from remotely sensed imagery and annual polygon overlays. They do not directly measure erosion rate, scour depth, bank stability, sediment thickness, pipeline burial depth, or structural integrity. Consequently, the presented indicators should be considered as spatial screening and monitoring tools rather than direct engineering assessment parameters.

Several sources of uncertainty should also be considered. The analysed satellite images were acquired during different years and potentially under different hydrological conditions. Variations in seasonal water level, image resolution, sediment moisture, vegetation cover, and illumination conditions may influence interpretation of water boundaries and exposed surfaces. Additional uncertainty may originate from manual digitization, simplification of polygon boundaries, and the use of watercourse boundaries as GIS-derived bank proxies. Furthermore, the study is based on planform interpretation and does not include bathymetric measurements, sediment thickness data, field-based bank surveys, or hydraulic modelling. Despite these limitations, the use of a fixed geomorphic AOI and a consistent multi-temporal GIS workflow provides a coherent basis for comparative spatial analysis of river corridor evolution.

Overall, the study demonstrates that multi-temporal GIS analysis can provide valuable insight into the spatial evolution of river crossings located within morphodynamically active environments. The proposed approach is particularly useful for long-term monitoring of riverine infrastructure corridors where repeated channel reconfiguration, island development, and flow redistribution may gradually modify the geomorphic context of the crossing area. In practical terms, the method can help identify crossing segments were additional field inspection, bathymetric survey, bankline monitoring, or pipeline-cover verification should be considered.

Conclusion

This study presented a multi-temporal GIS analysis of river channel migration near a pipeline crossing on the Kura River, Azerbaijan. Using satellite image interpretation and vector-based spatial analysis for 2001, 2007, 2009, 2010, 2012, and 2013, the study examined temporal changes in watercourse footprint, exposed in-channel ground, island structure, and the spatial relationship between the active river corridor and the pipeline crossing.

The results demonstrate that the investigated area experienced substantial channel reconfiguration during the observation period. The river corridor evolved through redistribution of active channel threads, expansion and restructuring of alluvial island surfaces, and localized narrowing of active water pathways. The increase in island fraction and near-bank pipeline indicators during the later epochs suggests that the crossing corridor became progressively more spatially constrained around the pipeline alignment.

One of the principal findings of the study is that the crossing should not be interpreted solely as a fixed engineering point intersecting a stable river channel. Instead, it should be considered part of a dynamically adjusting corridor in which changing relationships between water-covered and exposed surfaces continuously modify the spatial configuration of the crossing environment.

The proposed GIS workflow provides a reproducible framework for monitoring river corridor evolution using multi-temporal polygon overlays, area metrics, proximity indicators, and crossing-related spatial analysis. The methodology is intended primarily for GIS-based monitoring, spatial exposure screening, and prioritization of crossing segments that may require closer inspection. The derived indicators represent planimetric spatial relationships and should not be interpreted as direct measurements of pipeline exposure depth, bank failure, scour depth, or structural integrity.

Despite uncertainties associated with seasonal water conditions, image interpretation, variable image quality, and planform-based analysis, the study demonstrates that multi-temporal GIS methods can effectively identify long-term morphodynamic tendencies near river crossings. The approach may therefore support environmental monitoring and spatial assessment of riverine infrastructure corridors located within dynamically evolving alluvial systems. Future studies should integrate GIS-based analysis with field bankline surveys, water-level observations, bathymetric measurements, sediment and bank-material observations, and, where access is possible, pipeline-cover verification. Such validation would make it possible to distinguish more clearly between planimetric corridor reconfiguration and direct engineering exposure of buried infrastructure.

Competing interests

The authors declare that they have no competing interests.

ORCID iD

Aslan Babakhanov https://orcid.org/0000-0002-8790-7945

References

Ashmore, P. E. (1982). Laboratory modelling of gravel braided stream morphology. Earth Surface Processes and Landforms, 7(3), 201–225. https://doi.org/10.1002/esp.3290070301

Belletti, B., Rinaldi, M., Bussettini, M., Comiti, F., Gurnell, A. M., Mao, L., Nardi, L., & Vezza, P. (2017). Characterising physical habitats and fluvial hydromorphology: A new system for the survey and classification of river geomorphic units. Geomorphology, 283, 143–157. https://doi.org/10.1016/j.geomorph.2016.11.003

Church, M. (2006). Bed material transport and the morphology of alluvial river channels. Annual Review of Earth and Planetary Sciences, 34, 325–354. https://doi.org/10.1146/annurev.earth.33.092203.122721

Fryirs, K., & Brierley, G. J. (2013). Geomorphic analysis of river systems: An approach to reading the landscape. Wiley-Blackwell.

Gilvear, D. J., & Bryant, R. G. (2016). Analysis of aerial photography and other remotely sensed data for fluvial geomorphology and river science. In G. M. Kondolf & H. Piégay (Eds.), Tools in fluvial geomorphology (2nd ed., pp. 103–132). John Wiley & Sons. https://doi.org/10.1002/9781118648551.ch6

Gurnell, A. M., Petts, G. E., Hannah, D. M., Smith, B. P. G., Edwards, P. J., Kollmann, J., Ward, J. V., & Tockner, K. (2001). Island-dominated landscapes of large floodplain rivers, a European perspective. Freshwater Biology, 46(4), 581–600. https://doi.org/10.1046/j.1365-2427.2001.00692.x

Hicks, D. M., Duncan, M. J., Lane, S. T., Tal, M., & Westaway, R. M. (2008). Contemporary morphological change in braided gravel-bed rivers: New developments from field and laboratory studies, with particular reference to the influence of riparian vegetation. In H. Habersack, H. Piégay, & M. Rinaldi (Eds.). Gravel-bed rivers VI: From process understanding to river restoration, (Developments in Earth Surface Processes, Vol. 11, pp. 557–584). Elsevier.

Hooke, J. M. (2007). Spatial variability, mechanisms and propagation of change in an active meandering river. Geomorphology, 84(3–4), 277–296. https://doi.org/10.1016/j.geomorph.2006.06.005

Lane, S. N. (2017). Natural flood management. WIREs Water, 4(3), e1211. https://doi.org/10.1002/wat2.1211

Makaske, B. (2001). Anastomosing rivers: A review of their classification, origin and sedimentary products. Earth-Science Reviews, 53(3–4), 149–196. https://doi.org/10.1016/S0012-8252(00)00038-6

Piégay, H., Darby, S. E., Mosselman, E., & Surian, N. (2005). A review of techniques available for delimiting the erodible river corridor: A sustainable approach to managing bank erosion. River Research and Applications, 21(7), 773–789. https://doi.org/10.1002/rra.881

Piégay, H., Arnaud, F., Belletti, B., Bertrand, M., Bizzi, S., Carbonneau, P., Dufour, S., Liébault, F., Ruiz-Villanueva, V., & Slater, L. (2020). Remotely sensed rivers in the Anthropocene: State of the art and prospects. Earth Surface Processes and Landforms, 45(1), 157–188. https://doi.org/10.1002/esp.4787

Rapp, C. F., & Abbe, T. B. (2003). A framework for delineating channel migration zones. Washington State Department of Ecology and Washington State Department of Transportation.

Surian, N., Ziliani, L., Comiti, F., Lenzi, M. A., & Mao, L. (2009). Channel adjustments and alteration of sediment fluxes in gravel-bed rivers of north-eastern Italy: Potentials and limitations for channel recovery. River Research and Applications, 25(5), 551–567. https://doi.org/10.1002/rra.1231

Paleoclimate and Archaeological Foundations of the Proposed Iori Upland Geopark

Zurab Janelidze[1,*], Giorgi Janelidze[1]

[1] Ilia State University, Tbilisi, Georgia

Georgian Geographical Journal, 2026, 6(1) 45-49

DOI:
https://journals.4science.ge/index.php/GGJ

Citation: Janelidze, Z.; Janelidze, G. Paleoclimate and Archaeological Foundations of the Proposed Iori Upland Geopark. *Georgian Geographical Journal* 2026, 6(1), 45-49. https://doi.org/10.52340/ggj.2026.06.01.06

* Corresponding author:

zurab_janelidze@iliauni.edu.ge

Abstract

The proposed Iori Upland Geopark represents one of the most distinctive areas of Georgia, combining exceptional geological, geomorphological, archaeological, and ecological heritage within a single landscape. This study aims to evaluate the paleogeography, paleoclimate, and archaeological foundations that support the scientific justification for establishing the geopark and to demonstrate their importance for geoheritage conservation, sustainable development, and geotourism. A multidisciplinary approach was employed, integrating literature review, paleogeography and paleoclimate reconstruction, archaeological analysis, comparative assessment, and Geographic Information System (GIS)-based spatial analysis. Geological, geomorphological, archaeological, and environmental datasets were synthesized to reconstruct the long-term evolution of the Iori Upland and examine interactions between environmental processes and human occupation. The results indicate that the region preserves an outstanding record of landscape evolution from the Neogene through the Holocene, reflected in its geological formations, semi-arid ecosystems, and numerous archaeological monuments. Evidence suggests that the onset of desertification predates modern climate change and was primarily driven by extensive anthropogenic landscape transformation, particularly deforestation and intensive land use, which altered hydrological regimes and accelerated ecosystem degradation. Archaeological records further demonstrate continuous human occupation since the Bronze Age and reveal the close relationship between environmental change and cultural development. The integration of geological, climatic, ecological, and archaeological evidence confirms the exceptional scientific and educational value of the Iori Upland and highlights its potential as a geopark of national and international significance. Establishing the geopark would contribute to the conservation of Georgia's geoheritage, strengthen interdisciplinary research, support environmental education, and promote sustainable geotourism while enhancing public awareness of long-term landscape evolution and the impacts of climate and human activities.

Keywords: Iori Upland Geopark, Paleogeography, Paleoclimate, Desertification, Archaeological heritage

Introduction

Geoparks are geographical areas possessing outstanding geological, geomorphological, palaeontological, and cultural heritage, the protection, study and sustainable use of which is considered one of the important priorities of contemporary environmental management. The scientific basis for the establishment of the Iori Upland Geopark is based on the long history of the geological development of the territory, for the reconstruction of which paleogeography and paleoclimate studies are of particular importance. These studies provide the basis for understanding to determine the natural processes and environmental conditions that have created the modern landscapes, geological structures and unique complexes of biodiversity of the Iori Upland over millions of years.

Paleogeography factors in the study area reflect changes in the relief surface, including sea transgressions and regressions, the formation of sedimentary basins and the evolution of the relief. As a result of these processes, many unique geological objects were formed, which today represent the main resource of the planned geopark. At the same time, paleoclimate changes had a significant impact on erosion, accumulation and denudation processes, which determined the transformation of landscapes, the formation of soil cover and the development of ecosystems.

In the concept of creating the Iori Upland Planned Geopark, the paleogeography and paleoclimate heritage is not only a source reflecting the history of the development of the natural environment, but also an important basis for the protection of geoheritage, scientific research, educational activities and the development of geotourism. Therefore, in the scientific justification of the geopark, particular attention was given to the study of those historical-geological and paleoclimate events that determined the uniqueness of a specific territory and its international significance.

Methods and Materials

The present study is based on a complex analysis of paleogeography, paleoclimate and archaeological factors important for the formation and scientific substantiation of the Iori upland. Both theoretical and empirical methods were used in the research process.

Literature review – international and local scientific publications, monographs, reports and legislative documents were studied, which relate to the concept of geoparks, paleogeography reconstructions, paleoclimate changes and cultural heritage protection. This method was used to determine the theoretical foundations of the study and evaluate the experience of different countries in establishing geoparks.

Paleogeography analysis – the geological structure of the territory, the history of relief development, the history of the study of sedimentary rocks, fossil material and geomorphological forms was collected. Based on this data, important stages of the geological past of the territory and their connection with modern landscapes were reconstructed.

Paleoclimate reconstruction – the analysis of existing paleoclimate data was used, including the results of palynological (pollen grains), paleobotanical, sedimentary deposits and isotopic studies. This method enabled the identification of the impact of climate change on the formation of landscapes, ecosystems and early human settlements.

Archaeological data analysis – materials obtained from archaeological sites, cultural layers, historical settlements and samples of material culture were studied. The analysis of archaeological material enabled to determine the relationship between human activity and the natural environment in various historical periods.

Cartographic and GIS-based analysis – analysis of topographic, geological, landscape and archaeological maps was used, as well as the capabilities of Geographic Information Systems (GIS) for processing and visualization of spatial data. Spatial integration of geoheritage, archaeological objects and paleoenvironmental indicators was carried out using GIS technologies.

Comparative analysis method – based on the comparison of examples from different regions and geoparks, the role of paleogeography, paleoclimate and archaeological heritage in the process of creating and developing geoparks was assessed.

The combination of the applied methods provided a multifaceted assessment of the natural and cultural heritage of the study area, which is an important foundation for the scientific justification of the creation of a geopark.

Results and Discussions

The Iori Upland Planned geopark is a unique natural and cultural heritage area of Georgia, where the diversity of arid landscapes, the dynamics of natural processes and the traces of centuries-old human activity are particularly evident. The study area is distinguished by the spread of semi-desert and steppe ecosystems, which gives the region distinctive geographical significance compared to other regions of Georgia. Against the background of modern environmental challenges, the study of desertification processes is particularly relevant, since climate change, soil degradation and anthropogenic impact have a significant impact on the natural environment of the Iori Upland.

The territory of the Planned geopark is also rich in historical and archaeological monuments, which clearly reflect human adaptation to difficult natural conditions and the centuries-old history of cultural development in the region. The ancient settlements, burial grounds, cult buildings and other cultural heritage sites present here are an important scientific source for studying the history of both Georgia and the Caucasus. In addition, the Iori Plateau is distinguished by its biodiversity - a number of endemic and rare species of plants and animals are found in the region, which are adapted to dry and harsh environmental conditions. It is precisely the combination of natural, geological, historical-cultural and ecological values that defines the scientific significance of the Iori Plateau Geopark and determines the necessity of its research, protection and sustainable development. Of the many factors for creating a geopark on the Iori Plateau, the paleoclimate factor is important, because the formation and development of the landscape on the Iori Plateau, together with the anthropogenic factor, is determined by long-term and variable paleoclimate processes that have been developing since the Neogene period to the present day. Anthropogenic processes played a special role in the formation of modern landscapes during the Lower Holocene and especially during the Iron Age and Early Antiquity.

The intensification of the desertification process in semi-arid and partially subhumid regions, where the steppe, forest-steppe, savannah and forest biocenoses are being replaced by semi-desert and desert biocenoses. The importance of this problem is evidenced by the fact that in 1994 the United Nations adopted a special Convention on Desertification (United Nations…, 1994). The Convention also mentions Transcaucasia among the various regions of the world that are threatened with desertification. The main reason for the intensification of the desertification process is considered to be modern global warming and the negative impact of the anthropogenic factor on natural landscapes (Kiguradze, 1976).

In Transcaucasia, the desertification process is observed in the eastern part of its intermontane plain – the Mtkvari-Araks lowland and the adjacent foothills. In the eastern part of Georgia, this process is taking place in the Kvemo Kartli plain (Rustavi-Gardabani and Marneuli plains with the adjacent foothills) and on the Iori plateau (Gareja-Iori physical-geographical sub-district, Eldari plain, etc.).

The Gareja-Iori physical-geographical subregion (where the creation of the Ivor Upland Geopark is envisaged), which is located at an altitude of 300-900 m above sea level, is characterized by a hot and dry climate and a sharp deficit of precipitation. The study area is bordered by the Ivor River in the north and northeast, and its southern border coincides with the state border of Georgia and Azerbaijan. The relief of the Gareja-Iori subregion is represented by monoclinic mountains, strongly dissected by erosion-denudation processes, quester ridges and synclinal plains-tapas located between them. The annual total of atmospheric precipitation in this subregion does not exceed 400 mm, and evaporation reaches 1000 mm (Ukleba, 1968). Accordingly, the humidity coefficient is low, the annual rate of which is 0.50-0.65, and in summer - 0.20-0.30. In hot and dry climate conditions, the Gareja-Iori sub-district is devoid of permanent rivers and fresh springs. The presence of saline springs and brackish lakes is noted here and there. In the southern part of the sub-district (the mountains and ridges of the Great Desert, Desert, Yailajikha, Alajadara Taphobi) secondary dry fields, scattered xerophytic shrubs, semi-desert and partially desert Uroyan-Avshnian, Khurkhumoyan Avshnian and Choronyan-Avshnian plant associations are developed. In the central part (the desert plain, along with the surrounding hills and hills), floristically impoverished secondary steppe coenoses are represented, partly created by herbaceous species typical of semi-deserts, while in the northern part (the mountains and seres of Demurdal, Midlad, Natamarigori, Uzundara, Dzhikur and other plains and taphobys) – secondary jag-thorn-sedge-bark fields and xerophytic shrubs (Ketskhoveli, 1960; Ukleba, 1968).

The results of paleogeography and geobotanical studies (Ketskhveli, 1960; Vekua, 1984; Gogichaishvili, 1984) indicate that the process of desertification on the Iori plateau began much earlier than modern global warming and was due not to natural aridization of the climate, but to the strong impact of the anthropogenic factor on natural landscapes. It has been established that in the territories of the Gareja-Iori sub-district in the middle Holocene (4000-6000 years ago) broad-leaved (mainly oak-hornbeam forests), floodplain and arid sparse forests, steppe and meadow landscapes were widespread. The main edificators of forests - oak, hornbeam, sakmlishche and others, are currently preserved only as derivatives in single specimens here and there among the bushes of privet and fruit trees. The widespread distribution of forest coenoses in the past is also indicated by the fact that the black soil, chestnut and Russian-brown soils of the Kvemo Kartli Plain and Gareja-Iori sub-district have preserved signs of transition from forest soils to dry field and semi-desert soils. Traces of the development of soil-forming processes characteristic of dry field and semi-desert soils are more prevalent in these soils. This fact is explained by the rather long-standing spread of semi-desert and partially desert vegetation from the east (from the Mtkvar-Araks lowland) in these regions (Sabashvili, 1965; Nakaidze, 1979).

In recent decades, about two dozen archaeological sites (cities, burial mounds, kurgan burials) of all stages of the Bronze Age (second half of the 4th millennium BC - the end of the 2nd millennium BC) and the Early Iron Age (beginning of the 1st millennium BC) have been discovered in the Gareja-Iori sub-districts. The study of these sites has confirmed that the territory of the Gareja-Iori sub-district was completely inhabited by humans from the second half of the 4th millennium BC to the beginning of the ancient period (Kakheti, 2005). The ancient population of this sub-district had highly developed agriculture and animal husbandry, and metallurgical activities (iron smelting and export) were the main lever of its economic development. It is noteworthy that the “Naoamari Gori” settlement discovered in the Gareja-Iori sub-district, whose age, according to a series of radiocarbon dates, is determined to be 12th-11th centuries BC, is so far the only monument of the 2nd millennium BC in the Caucasus whose stone architecture (a 1 km long and 5-6 m wide stone wall, etc.) is well preserved.

The available evidence suggests that the desertification process on the Iori Plateau began much earlier than modern global warming and was mainly due not to the natural aridification of the climate, but to the impact of irreversible anthropogenic modification of the natural landscapes of this region. The growing anthropogenic load on natural landscapes led, first of all, to deforestation, and, consequently, to a sharp aridification of the climate. The previously existing ratio between temperature in the soil and surface layers of the air and atmospheric precipitation was gradually disrupted, evaporation increased, soil moisture content decreased, and a negative moisture balance was formed. Paleogeography and paleobotanical data show that by the beginning of the ancient period, a hydroclimatic regime characteristic of a dry plain and semi-desert had already been established on a significant part of the territories of the Gareja-Iori sub-district, which gave rise to the beginning and development of the desertification process. The desertification process in these regions was first manifested from the east - from the Mtkvar-Araks lowland through the Eldari plain - by the spread of semi-desert and desert vegetation formations (Avshnian, Karaghani, Khurkhumoyan, etc.).

The negative impact of the development of the desertification process on the living conditions of the ancient population is clearly visible on the example of the Gareja-Iori physical-geographic sub-district. The evidence suggests that the need for fresh water of the ancient population of this sub-district should have been completely provided by local fresh springs. The sharp aridization of the climate led to the intensification of the process of leaching of easily soluble salts from the Neogene rocks of the sub-district's surface and, consequently, the transformation of fresh springs into brackish springs. This fact, together with the aridization of the climate, must have been one of the reasons why the permanent population gradually left the Gareja-Iori sub-district in antiquity. Here, only the Gareja monastery monuments founded in the 6th century AD continue to have uninterrupted monastic life.

Currently, the scale of the negative impact of human economic activity (agriculture, animal husbandry, improper land reclamation, etc.) on the landscapes of the Gareja-Iori sub-district far exceeds the self-recovery capabilities of the ecosystems of these regions. Due to this, a more or less irreversible process of ecosystem degradation and desertification is underway. The desertification process in these regions is so obvious that even in the floodplain forests that still remain as separate massifs, desert elements are being intruded. It is clear that, along with the anthropogenic factor, modern global warming also creates favorable conditions for the development of the desertification process in these regions.

Modern studies show that the Iori Plateau remains a region particularly sensitive to climate change, where increasing temperatures and decreasing precipitation may further enhance the expansion of arid landscapes in the future.

Conclusion

The creation and development of the Iori Upland Planned geopark is based on the complex combination of natural and cultural heritage that reflects the evolution of a specific territory. In this process, as we have noted, special importance is attached to paleogeography, paleoclimate and archaeological factors, since it is their interaction that creates the scientific, educational and tourist value of the geopark.

Paleogeography studies allow us to restore the geological past of the territory, identify the stages of relief formation and assess the role of natural processes that have shaped modern landscapes. Paleoclimate data provide information about past climatic conditions, environmental transformation and adaptation of natural systems, which is especially relevant against the backdrop of modern climate change. In addition, archaeological heritage confirms the centuries-old relationship of man with the environment and demonstrates the ways in which natural resources and landscapes have influenced the development of society.

Within the framework of the Iori Upland Planned geopark, the above-mentioned components create a single space where natural history and human history are closely interconnected. Their protection and popularization will contribute not only to the preservation of geoheritage, but also to the deepening of scientific research, strengthening of education and the development of sustainable tourism. Accordingly, an integrated assessment of paleogeography, paleoclimate and archaeological heritage is one of the main scientific foundations for the creation and functioning of the Iori Upland Planned geopark, which determines their local, national and international significance.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

All authors provided critical feedback and helped shape the research, analysis and manuscript.

ORCID iD

Zurab Janelidze https://orcid.org/0000-0003-2608-8031

References

Gogichaishvili, L. (1984). The vegetation of the lowlands and foothills of Kvemo Kartli during the Holocene. In Man and His Environment. Tbilisi.

Kakheti. (2005). Kakheti: A generalized work on the past and present of Kakheti. Tbilisi.

Ketskhoveli, N. (1960). Vegetation of Georgia. Academy of Sciences of the Georgian SSR. Tbilisi.

Nakaidze, E. (1979). The gray-brown soils of Georgia. In "Genetic Types of Soils of the Subtropics of Transcaucasia". Moscow.

Kiguradze, T. (1976). Periodization of the early agricultural culture of Eastern Transcaucasia. Tbilisi.

Sabashvili, M. (1965). Soils of the Georgian SSR. Tbilisi.

Ukleba, D. (1968). Physical-geographical zoning of Eastern Georgia. Tbilisi.

United Nations. (1994). United Nations Convention to Combat Desertification. Paris, France.

Vekua, A. (1984). The fauna of Eastern Georgia during the Eneolithic period based on materials from the settlement of Arukhlo (6th–4th millennium BC). In "Man and His Environment". Tbilisi.

Cartographic Representation of Population Census Registers (According to Census Books of II Half of 17th Century)

Georgian Geographical Journal, 2026, 6(1) 1-15

DOI:
https://journals.4science.ge/index.php/GGJ

Dali Nikolaishvili[1,*], Mariam Shanava[1,2]

[1] Faculty of Exact and Natura Sciences, Department of Geography, TSU. Tbilisi, Georgia

[2] Akaki Tsereteli State University, Faculty of Exact and Natura Sciences, Department of Geography. Kutaisi, Georgia

* Corresponding author:

Citation: Nikolaishvili, D.; Shanava, M. Cartographic Representation of Population Census Registers (According to Census Books of II Half of 17th Century). *Georgian Geographical Journal* 2026, 6(5), 50-58. https://doi.org/10.52340/ggj.2026.06.01.07

mariam.shanava96@gmail.com

Abstract

Population census registers are among the most important historical sources, offering broad opportunities for studying the demographic, social, economic, and cultural development of society. Through them, it is possible to identify population size, social strata, settlement networks, taxation systems, and anthroponymic characteristics. Particular importance is attached to the historical-cartographic analysis of such data, as it enables the reconstruction of past spatial realities. The aim of this study is to analyze the data from the population census registers of Kartli in the 17th-18th centuries and to map them demographically. The research is based on the registers of the Zemo Kartli (Upper Kartli) military-administrative district (Sadrosho) from the second half of the 17th century and the 1715 register of the Ruisi Samtskso (Ruisi Parish), published in the works of Ivane Javakhishvili and Ekvtime Takaishvili. The study employs retrospective cartographic methods, historical-comparative and semantic analysis, GIS technologies, historical maps, toponymic evidence, and modern statistical data. As a result of the research, villages were identified and localized, and thematic maps were produced. During the research it was established that in 1715, the territory of the Ruisi Parish contained 87 villages and approximately 2,000 households. The population was unevenly distributed, with both relatively large and small settlements, including settlements undergoing decline. A dispersed settlement system and a tendency toward village abandonment were identified. Anthroponymic analysis shows that the naming system was characterized simultaneously by diversity and cultural uniformity. The most common names were Giorgi, Datuna, Tamaza, Ivana/Ivane, and others. The study confirms that population census registers constitute an important source not only for history, demography, and ethnography, but also for historical cartography. Through their analysis and the use of GIS technologies, it becomes possible to reconstruct historical space and determine the dynamics of settlement network development as well as the characteristics of territorial population distribution.

Keywords: Population census registers, historical cartography, retrospective analysis, Zemo Kartli, 17th century, Georgia

Introduction

Population census registers are among the most reliable and valuable sources, providing a comprehensive picture of the past development of society and its trends. Their value can be examined from several perspectives. First, they provide accurate information about population size, territorial distribution, ethnic and confessional structure, as well as sex-age composition and social status. On the other hand, population census registers are also important for the study of economic history. Census records frequently document people's occupations (for example, farmers, craftsmen, merchants, and others), which enables researchers to determine the general structure of the economy and the level of development of its individual sectors. They also enable researchers to identify linguistic substrata and assess the degree of linguistic assimilation, as well as to determine the characteristics of territorial population distribution, including population concentration and changes in settlement networks over time.

Population census registers are important not only for the study of the past, but also have practical applications in contemporary life, serving as sources of legal, scientific, and cultural significance. Through them, it is possible to:

- To determine historical changes in political and administrative boundaries, as well as in the boundaries of villages and cities;
- To Determine historical changes in political and administrative boundaries, as well as in the boundaries of villages and cities;
- To identify hereditary property rights and legal relationships (old registers often contain information about who owned land or lived in a specific territory), which may be significant in resolving contemporary disputes;
- To restore historical justice (for example, identifying repressed or forcibly resettled populations);
- To identify historical geographical names and establishing their correct spelling;
- To study the history of specific family names, ancestors, and kinship ties (census registers often contain lists of family members).

Moreover, by comparing historical and modern data, it becomes possible to identify demographic trends, which, in turn, provide a basis for proper future planning.

Thus, due to the wide range of issues they address, population census registers are valuable sources for historians, ethnographers, geographers, economists, linguists, and specialists in other fields.

Population census registers are also an important source for historical cartography. They provide the possibility to address and cartographically represent a range of issues within this scientific discipline.

Historical cartography, as an interdisciplinary field developing at the intersection of cartography and historical geography, aims to create of historical maps and atlases, the development of methodologies for their production, and the analysis of spatial distribution patterns of objects depicted on maps. However, in Georgia, historical cartography is considered a relatively underdeveloped discipline (Nikolaishvili et al., 2011, p. 33).

For Georgian historians, cartographers, and geographers, the work of Ivane Javakhishvili, which encompasses ancient population censuses and fiscal registers of Georgia, represents a highly important and fundamental source. In the very first chapter of the fourth volume, the scholar describes the approaches and procedures of population enumeration in feudal Georgia. In the II half of XVIII century Georgia, there were 4 Sadrosho (banner / military banner district), which functioned as military-administrative units, each governed by a different commander (Essays on the History of Georgia, 1973). These Banners units also served as census/registration units.

The aim of this study is to analyze the data from the population census registers of Kartli in the 17th-18th centuries and to map them demographically. On the basis of this analysis, the collected data are organized according to settlement systems, quantitative and structural characteristics of the population, forms of economic activity, and features of historical development. An important direction of the research is the identification of methodological principles for the cartographic representation and visualization of census registers, so that they can be used to ensure spatial analysis of historical-demographic, historical-ethnographic, and historical-geographical processes.

Methods and Materials

The study employs a retrospective cartographic method, which enables the reconstruction of past spatial realities and their representation on maps based on both modern and historical spatial data. For this purpose, a variety of sources were used in combination: historical documents, census registers, old maps, modern toponymy, and relevant scholarly literature on the subject. Through analysis and comparison of these data, the historical spatial patterns is reconstructed. Specifically, based on the analysis of settlements and population figures, a series of thematic maps was created. This involved the identification, systematization, and classification of data contained in the census registers, comparative analysis of datasets, the creation of a GIS database, the development of appropriate cartographic symbols, and the compilation of a series of thematic maps.

The presented work is primarily based on the registers included in the work of Ivane Javakhishvili, Economic History of Georgia (1930, 1996).

In addition, these registers were also used as sources.

The research was carried out in several stages:

- Stage I – Systematization of census data (compilation of a list of villages, creation of a digital dataset of household numbers);
- Stage II – Identification and localization of villages (comparison of historical village names with their modern equivalents, identification of forgotten or modified toponyms based on later sources, and determination of their locations using other scholarly sources and topographic maps). For this purpose, comparative, semantic, and other research methods were applied;
- Stage III – GIS geocoding and database creation (compilation of an attribute table based on census register data and modern datasets);
- Stage IV – Preparation and analysis of thematic maps using GIS (determination of the spatial distribution of settlements and population concentration, and their comparison with the contemporary situation).

In the feudal period, the territory of Georgia was divided into sadrosho (Banner) – military-administrative units: The Advance (Metsinave), Royal (Samepo), Right (Memarjvene), and Left (Memartskhene) Sadrosho. During both the unified Georgian kingdom and the period of its fragmentation into kingdoms and principalities, the territories and boundaries of these sadrosho and their constituent duchies (saeristavo) changed. Each of the kingdoms of Kartli, Kakheti, and Imereti had its own duchies. By the first half of the 17th century, the Kingdom of Kartli already included the Advance (Metsinave, in Lower Kartli), Royal (Samepo), Left (Memartskhene in Mukhrani), and Right (Memarjvene, in Upper Kartli) sadrosho (Atlas of the History of Georgia, 2016, p. 44).

The census books discussed in the article covered the territory of the Right – Upper Kartli Sadrosho.

Results

A general overview of the registers of the II half of the 18th century

In the II half of the 18th century, Georgia was in a complex historical situation. This was a period when the country experienced a severe demographic and economic crisis due to the difficult conditions caused by Ottoman pressure, Lekianoba (raids by Dagestani groups), and Qizilbash incursions. Furthermore, reforms were being initiated by the king, for which accurate statistical information was essential. In this context, the registers were of considerable practical importance in several respects. First, they had military-mobilizational significance: the data in the registers made it possible to determine how many combat-ready men existed in a given sadrosho and how many fighters each noble, noble family, or village could mobilize when necessary. Second, they had fiscal significance: the state treasury was replenished through taxes paid by the population, making it essential to accurately record the real number of taxpayers. Third, the registers also had a legal function, as they documented the attachment of serfs (kma-glekhni) to specific landlords or state lands. In this respect, the registers acquired additional importance by facilitating the search for and return of fugitive peasants (Javakhishvili, 1996, Vol. 4, p. 38).

The registers reflect the real situation of the population, which is expressed through the difficult socio-economic condition of the villages. At that time, large family households dominated in Kartli, meaning that several brothers lived together in one household with their wives and children. According to Ivane Javakhishvili, such a household structure and demographic arrangement made it easier for families to fulfill tax obligations. In addition to this economic strategy, living in large extended families also had a defensive function, as it facilitated resistance against enemy invasions (Javakhishvili, 1996, Vol. 4, p. 42).

The registers clearly distinguish different categories of peasantry. For example, “mkvidri” (settled/owned peasants) or purchased peasants (nasqidi), and old serfs, who were hereditarily tied to the land and could not change their place of residence without the consent of their feudal lord. This status was inherited and passed down from ancestors to their children. Another category includes “bogano” and “khizani”. These groups did not possess their own land; they were mainly resettled or displaced populations, often taking refuge in other areas. Their legal and social status was still not fully defined during this period.

The registers also mention the branches of agriculture practiced by the population of Upper Kartli at that time. These included arable farming (with wheat and barley cultivation), viticulture (notably, the registers also record taxes levied on wine), animal husbandry, and other related economic activities.

An analysis of the registers shows that they mainly contain descriptions of the villages of the dioceses and the population settled there, i.e., the parish (mrevli). The number of households (komli) is listed according to villages. In the household lists, the name of the head of the family is indicated, as well as the names of his children, brothers, and even other relatives. Their social status is also recorded, specifying whether the person is a settled peasant (mkvidri), a migrant/tenant peasant (khizani), or a landless poor person (bogano).

However, it should be noted that there are certain discrepancies between the Upper Kartli registers and the parish registers. For example, Ivane Javakhshvili points out that the register of the Upper Kartli sadrosho is likely earlier than the 1715 parish register. For instance, in the sadrosho register, in the village of Abano, the following is mentioned: “Bezishtashvili Paata, one household; his brothers Gurgena, Datuna, Ivana, and their four sons.” In the 1715 parish register, however, Bezishtashvili Paata no longer appears, while Ivane is recorded as a separate household head, and his grandson Ivane, “Ivanashvili Ivane,” is also listed separately as an independent household head (Takaishvili, 1907, p. 171). Despite certain shortcomings, these data still provide a valuable demographic picture, which can be used to estimate the population of villages at the time and to map population density. Accordingly, it can once again be emphasized that census registers are not only an important foundation for historical-geographical research, but also a key resource for the further development of historical cartography.

Overview of the Registers of the Upper Kartli Sadrosho of the II Half of the 17th Century and the Ruisi Parish Census of 1715

Ivane Javakhishvili provided extensive analysis of numerous population registers, including those of the Upper Kartli Sadrosho from the 17th-18th centuries (Fig. 1). These registers are of particular importance, as they represent one of the oldest known demographic-statistical monuments in the Georgian historical space. The documents demonstrate that, by that period, an organized system of population registration already existed in Kartli. The census records were structured by villages, social groups, and household units, indicating a relatively advanced administrative framework. This organization reflects the active role of both the state and feudal authorities, as well as the church, in controlling the population. They assessed military and fiscal resources and maintained detailed knowledge of the social composition of each village.

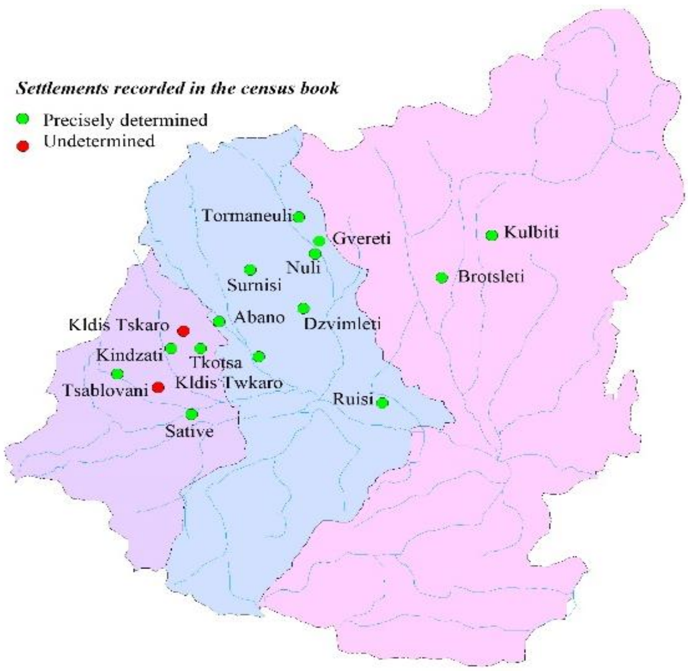


Figure 1. Settlements according to Zemo Kartli Sadrosho

The 17th-century census register of the Upper Kartli Sadrosho is considered the oldest surviving Georgian population register. The data are organized according to the villages within the territory of the Upper Kartli Sadrosho. Frequently encountered terms include: „salashkro vaji“ (military service male), „Nasheni vaji“ (native-born male), „zma“ (brother), and „zmiswuli“ (nephew), which clearly reflect both the military potential of the population and the structure of large patriarchal family units.

The register is also characterized by a distinctive form of recording. The text is written in a continuous narrative style, and individual households are not clearly separated from one another. Only social groups are distinguished by lines of separation (Javakhishvili, 1930/1996). This demonstrates that Georgian administrative practice was still in the process of development and differed from later, more refined census registers. A significant place in the document is also given to genealogical descriptions of the population. Family members, brothers, sons, and descendants are frequently mentioned, which gives this source considerable importance for the study of Georgian surnames, family structures, and demographic processes.

The register clearly reflects the social hierarchy of Kartli society. The village community was not homogeneous. The population is divided into groups such as „mokalne msakhlebeli“ (resident laborers), „Bogano“ (vagrants), „Msakhuri and Glexi“ (servants and peasants), and „meulufe and mesefe“ (royal steward and royal servant), indicating the existence of relatively free peasantry, dependent peasantry, a service class, and groups closely tied to land and lordship (Table 1).

Table 1. General similarities and differences between the census books of the Upper Kartli Sadrosho (II half of the 17th century) and the 1715 Ruisi Samtskso

Date of census	II half of the 17th century	1715
Aim of census	Population census	
	State-military	Ecclesiastical-taxation
Objects of enumeration	Households with male population only	
Order of enumeration objects	The population is organized by villages	
Feudal hierarchy	Mokalne (resident holder) Bogano (Vagrant) Servant Peasant Meulupe (royal steward) Mesepe (royal servant)	Tarkhan (tax exemption) Mobegre (taxpayer) Bogano (Vagrant „Other“ (heir)
Church influence	Is less noticeable	Is clearly visible

Only the male population is included in the census records. This is not incidental, as the primary concern of Georgian state practice was the assessment of military manpower, the number of able-bodied men, and the determination of taxable units.

The 1715 Samrevlo Register, i.e. the Ruisi Samtskso Census, was compiled by order of Bishop Nikoloz Mroveli (Orbelishvili / Kaplanshvili) (Ivane Javakhishvili, 1996). It was published by Ekvtime Taqaishvili in 1907, who notes that „Each family or household is recorded by surname and personal name, and not each individual person separately“ (Takaishvili, 1907, p. 207), meaning that the register is essentially a list of households (komli). According to Ivane Javakhishvili, the register includes the entire population of the parish (Javakhishvili, 1930, p. 11). He further cites Bishop Nikoloz Mroveli’s statement that the purpose of the census was fiscal: „I recorded it for the drami, so that the revenue of the church would not be lost“. This reflects that the primary aim of the register was to determine the income of the Ruisi episcopal see (sakhdomo). Thus, the main function of the register was fiscal, as it was created primarily for the assessment of parish revenues.

The 1715 Ruisi Samtksko Register functioned as an instrument of financial control, as clearly indicated by the text itself: „I recorded it for the drami, so that the revenue of the church would not be lost“. This statement demonstrates that the Church sought to precisely determine who was liable for which taxes, how much income the episcopal see generated, and the status of each household. In addition, the Church recorded not only serfs but the entire ecclesiastical parish population. Therefore, the register provides an overall fiscal picture of the community, reflecting its complete taxation structure.

According to the register, the population was divided into 2 main groups: Tarkhans and Mobeghre (peasant liable for labor service). A tarkhan was a person who was exempt from regular taxation and, instead of paying taxes, was obliged to provide service; such individuals enjoyed certain privileges and did not pay the full burden of dues. In the register, they are referred to with expressions such as „has a sacrificial obligation“ or „has a memorial obligation“, indicating their privileged fiscal status. In contrast, a mobeghre was a regular taxpayer who paid standard obligations such as drami, cod of grain, and shaurs (small coin). The register also shows differentiation in the amount of taxation according to economic status: Bogano – the poorest segment of the population with limited property – paid ½ a kodi (meseare of grain), whereas others paid a full kode.

Table 2. Correspondence of village's names in the Ruisi Samtskso with their modern equivalents

Name of villages	20002 / 2014	Municipal - Community affiliation
Abano	Abano	Kareli
Brotsleti	Brotsleti	Gori
Zemo Dzvileti	Zemo Dzvileti	
Tormaneuli	Tormaneuli	
Kldis Tskaro	KldistTskaro	Khashuri: Ali, Tsagvli
Kulbiti	Kulbiti	
Nuli	Nuli (former village	Kareli
Ruisi	Ruisi	Kareli
Sative	Patara Sative	Khashuri
Surnisi	Sunisi	
Tskotsa	Tskotsa	Khashuri
Ptsa	Ptsa	Kareli
Kvemo Dzvileti	Kvemo Dzvileti	
Kindzati	Kindzati	Khashuri
Gvereti	Gvereti	
Tsablovani	Tsablovana	Khashuri

The nobility and the princes and nobles class (Tavadi, Aznauri) are not included in the register. According to Ivane Javakhishvili, they had different types of obligations and did not fall within the general taxation system, instead performing other forms of service-based duties (Javakhishvili, 1930/1996). This clearly demonstrates the privileged structure of feudal society, where social stratification was directly reflected in fiscal and administrative practices.

Both registers represent important historical sources that provide valuable insight into the social, demographic, and administrative systems of 17th-18th century Georgia. Both are based on household (komli) enumeration and constitute a significant foundation for the study of social strata, fiscal obligations, and village organization. However, the register of the Upper Kartli Sadrosho has a more military-demographic and social character, with particular emphasis on family and kinship structures and population social categories. In contrast, the Samrovlo Register is primarily ecclesiastical-fiscal in nature and serves the economic interests of the Ruisi Bishopric, focusing on the documentation of the obligations of mobeghres and tarkhans.

Population mapping of the pastoral district register

According to the register, there were 87 villages in the Ruisi pastoral district, while the number of households was 1,972 (approximately 9,860 inhabitants). However, as E. Takaishvili notes, these data are not complete, since several pages are missing from the original manuscript. According to his calculation, “If we estimate even a minimum of five persons per household, the total would be 9,095 persons; if we also take the missing pages into account, then the entire Ruisi pastoral district would amount to nearly two thousand households, and the total population would exceed 10,000” (Takaishvili, 1907, p. 207). The incompleteness of the register is also discussed by Ivane Javakhishvili, who notes that “In the description of this numerous populations, information about the nobility is very rare” (Javakhishvili, 1930, p. 12). He also attempts to explain the probable reason for this omission, stating that “Instead of paying the drama tax and performing service, the nobility had other obligations imposed upon them” (Javakhishvili, 1930, p. 12).

Despite the gaps in the data, the register provides a fairly clear picture of the population size and the peculiarities of its territorial distribution, including villages and abandoned settlements, the social structure (such as the Bogano, village headman, and priest), the economic condition (household tax), anthroponyms (personal names), and other aspects.

The data included in the register corresponds to the territories of three modern municipalities: Borjomi, Kareli and Khashuri Municipalities. Of these, 49 households (245 inhabitants), 36 households (180 inhabitants), and 2 households (10 inhabitants) belonged to each municipality, respectively (Table 2).

Table 3. Ten most widely distributed personal names (According to 1715 register of the Ruisi Samtskso)

Personal Names	Number of Personal Names	Number of Villages
Giorgi	198	64
Beri	192	61
Datuna	133	63
Tamaza	107	52
Ivana, Ivane	101	51
Papuna	69	38
Sekhni, Sekhnia	63	36
Mamuka	57	36
Paata	54	37
Zakara, Zakaria	43	30
Total	1017	468

The ten most widespread personal names belong to names traditionally used among Georgians. Some of these names are still found in the modern period (Table 3). In this regard, the most common name was "Giorgi" (Saint George-derived), which was borne by nearly 200 individuals across 64 villages.

Within the boundaries of the present-day Kareli Municipality, 49 villages are recorded, inhabited by 1,126 households, or approximately 5,630 people. The largest settlements were the villages of Atotsi and Bredza, each with 58 households, corresponding to about 290 inhabitants per village (620 inhabitants according to the 2014 census). They were followed by the village of Prinevi, with 57 households, or approximately 285 inhabitants (620 inhabitants according to the 2014 census). Two additional villages had more than 50 households: Tighva and Dvani. There were also very small settlements with fewer than 5–6 households. These included Aramgana, Arkniti, Metekhi, Mughni, Skhliti, Patkineti, Gharistavi, and Tsipliti.

Within the boundaries of the present-day Khashuri Municipality, 36 villages are recorded, inhabited by 776 households, or approximately 3,880 people. The largest settlement was the village of Tezeri, where 111 households lived, corresponding to about 555 inhabitants (620 inhabitants according to the 2014 census). In terms of population size, the village of Ruisi was considerably smaller than Tezeri, as were the other villages. Three additional villages had more than 40 households: Bekami with 45 households (approximately 225 inhabitants; 180 and 327 inhabitants in Greater and Lesser Bekami respectively, according to the 2014 census), Brili with 43 households (approximately 215 inhabitants; 101 inhabitants in 2014), and Itria with 42 households (approximately 210 inhabitants; today an abandoned settlement). Nearly 70% of the villages had between 10 and 40 households. These included Surami, Tkotsa, Vaka, Osiauri, Odzisi, and others. The smallest settlements (fewer than 10 households) were five villages: Zindisi (now abandoned), Monasteri, Kindzati, Nabakhtevi, and Gorati (now abandoned). The last of these had only 4 households. With the exception of the abandoned settlements, population numbers in all these villages had increased by the time of the 2014 census.

An analysis of the population figures shows that during this period, within the territories of the present-day Kareli Municipality and Khashuri Municipality, there were 49 villages inhabited by 1,126 households (approximately 5,630 people). This implies that settlement patterns were highly fragmented. There were both relatively large villages and very small settlements, some of which may have been partially depopulated or in decline, with the prospect of eventually turning into abandoned settlements. This points to the existence of a dispersed settlement system, meaning that the population was distributed quite unevenly across the territory.

The register contains more than 1,600 anthroponyms (personal names). Among them, the 10 most widespread names are Giorgi, Bera / Beri, Datuna, Tamaza, Ivana / Ivane, Papuna, Sekhnia, Zakara / Zakaria, Paata, and Mamuka (Table 4). The first five names are found in almost every settlement where the number of households exceeded 10. This pattern differs significantly from the modern situation. The only exception is the name "Giorgi", which points to its special cultural and religious significance, particularly due to the cult of Saint George in Georgian tradition.

Out of 36 villages, the names Giorgi, Datuna, and Tamaza are found in more than 20 villages, accounting for more than half of the total number of villages. This once again highlights the popularity of these names, showing that people tended to choose from a limited set of well-established names. This suggests the existence of a common social standard and cultural continuity.

There are around 80 names that appear in only one village. These are rare and unique names, most of which have not survived to the present day; this indicates a process of cultural filtering. Among them are names that are still used in the modern period (for example, Avtandil, Aleksi, Amiran, Gela, Gia, Elizbar, Zaza, Ioseb, Mirza, Murvan, Petre, and others), as well as names that have long since fallen into oblivion (such as Amoan, Gosita, Goshpar, Varmieli, Zakuta, Indua, Ruama, Rcheula, Fotskhveri, Dzama, Dzelia, Jasha, and others).

Table 4. Distribution of personal names by villages (According to 1715 register of the Ruisi Samtskso)

Number of Villages	Personal Names
> 25	Giorgi, Datuna
20-25	Tamaza
15-19	Bezhua, Beri, Iavana / Ivane, Paata, Papuna, Sekhni / Sekhnia
10-14	Bidzina / Bidzini, Zakara, Zakaria, Mamuka, Naskida
5-9	Basil / Basili, Bezhan, Ber / Bera, Beruka, Givi. Zurab / Zuraba, Tevdora / Tevdore, Katsia, Makhara, Nikoloz / Nikoloza / Nikolozi, Otia, Oatara / Otari, Ramaza, Saba, Sgio, Shoshita, Khosia
< 5	Others

In the described historical period, the system of personal naming, despite its numerical diversity, was functionally characterized by high concentration and structural uniformity. The presence of more than 1,600 anthroponyms across 36 settlements indicates potential diversity; however, likewise, a certain level of cultural homogeneity existed in the form of local traditions and individual naming practices.

This tendency reflects the conservative nature of society, where the choice of personal names was strongly determined by religious, cultural, and familial traditions.

Conclusion

Based on the data from the 1715 register, it can be concluded that the settlement system of the Ruisi Sadrosho at that time predominantly consisted of a network of small and fragmented villages. The population was unevenly distributed. The majority of settlements were small-scale villages with few households, indicating a predominantly agrarian, non-urbanized landscape. The village of Tezeri stands out as the largest settlement and likely served as one of the main centers of economic and social activity. The prevalence of villages with fewer than 10 households (such as Zindisi, Gorati, Nabakhtavi, the monastic settlement of Kinzati, and others) points to weakly developed settlements and a tendency toward village abandonment. In the subsequent historical period, as a result of various socio-historical processes, a further trend of settlements turning into deserted villages (deserted settlements) can be observed.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

All authors provided critical feedback and helped shape the research, analysis and manuscript.

ORCID iD

Dali Nikolaishvili https://orcid.org/0000-0002-6540-3682

References

Berdzenishvili, D. (1985). Studies in the historical geography of Georgia: Upper Kartli–Tori, Javakheti. Tbilisi, Georgia.

Essays on the history of Georgia (Vol. 4). (1973). Tbilisi, Georgia.

Javakhishvili, I. (1930). Economic history of Georgia (Book 1, 2nd rev. ed.). Kartuli Tsigni.

Javakhishvili, I. (1996). Economic history of Georgia. In Works in twelve volumes (Vol. 4). Tbilisi, Georgia.

Javakhishvili, I. (1983). History of the Georgian nation (Vol. 2). Tbilisi, Georgia.

Klimiashvili, A. (1966). The 1772 regulation of the Upper Kartli military detachment (Mdevari). Matsne, (1), 91–95.

Historical atlas of Georgia. (2016). Artanuji.

Maruashvili, L. (1964). Physical geography of Georgia. Tbilisi, Georgia.

Metreveli, S. (2023). Encyclopedic dictionary of Georgian hagiography (4th–10th centuries) (R. Metreveli & A. Arabuli, Eds.). National Academy of Sciences of Georgia.

Muskhelishvili, D. (1979). In Georgian Soviet Encyclopedia (Vol. 4, p. 511). Tbilisi, Georgia.

Nikolaishvili, D., Sartania, D., Ujmajuridze, A., Kirtadze, D., & Kvetenadze, M. (2011). Meskheti according to Ottoman registers. Universal Publishing.

Nikolaishvili, D., Sartania, D., Ujmajuridze, A., Kirtadze, D., & Kvetenadze, M. (2016). Samtskhe-Javakheti. Tbilisi, Georgia.

Takaishvili, E. (1907). Archaeological journeys and notes (Book 1). Publishing Association of Georgian Books.

Highlights of Romanian Caves and Karst

Gheorghe M.L. Ponta[1,*], Victor Ursu[2], Romeo A. Perlik[3]

[1] Geological Survey of Alabama, 420 Hackberry Lane, Tuscaloosa, Alabama, 35401, U.S.A

[2] www.speologie.org, 84 Ironwood Ct, Middletown, New Jersey, 07748, U.S.A

[3] Ministry of Justice, Predeal, L. Rebreanu 11, 505300, Romania

* Corresponding author: gponta@yahoo.com

Georgian Geographical Journal, 2026, 6(1) 59-66

DOI:
https://journals.4science.ge/index.php/GGJ

Citation: Ponta, G.M.L; Ursu, V.; Perlik, R.A. Highlights of Romanian Caves and Karst. *Georgian Geographical Journal* 2026, 6(1), 59-66. https://doi.org/10.52340/ggj.2026.06.01.08

Abstract

Romania with an area of 238,391 km2, located in Southeastern Europe, has a karstifiable area of about 5,500 km^2 (approx. 2.3%). A website, www.speologie.org, was set up to collect and centralize all cave-related data within the Romanian karst. It is an online searchable database of 8,645 identified caves with 1,042 km of surveyed passages. The web page was started by cavers and is open for community contributions. The data structure extends the systematic catalogue started by Cristian Goran in 1981. The diverse spectrum of Romanian caves is briefly presented in this paper.

Keywords: karst, caves, catalogue, recreational caving

Introduction

Romania, with an area of 238,391 km^2, is located in Southeastern Europe and is surrounded by the Black Sea and Moldova in the east, Serbia and Hungary in the west, and Ukraine in the North. The Danube (Dunărea) River forms most of the southern border with Serbia and Bulgaria.

The karstifiable rocks (limestones, dolomite, salt, gypsum) occupy about 5,500 km^2 (Onac and Cocean, 1996; Onac, 2000) of the Romanian territory (approx. 2.3%), and are Paleozoic, Mesozoic and Neogene deposits (Figure 1).

Romania has a temperate-continental climate, with four seasons, with average annual temperature ranging between 8 °C to 11 °C and precipitation between 600 mm to 1,010 mm per year. The

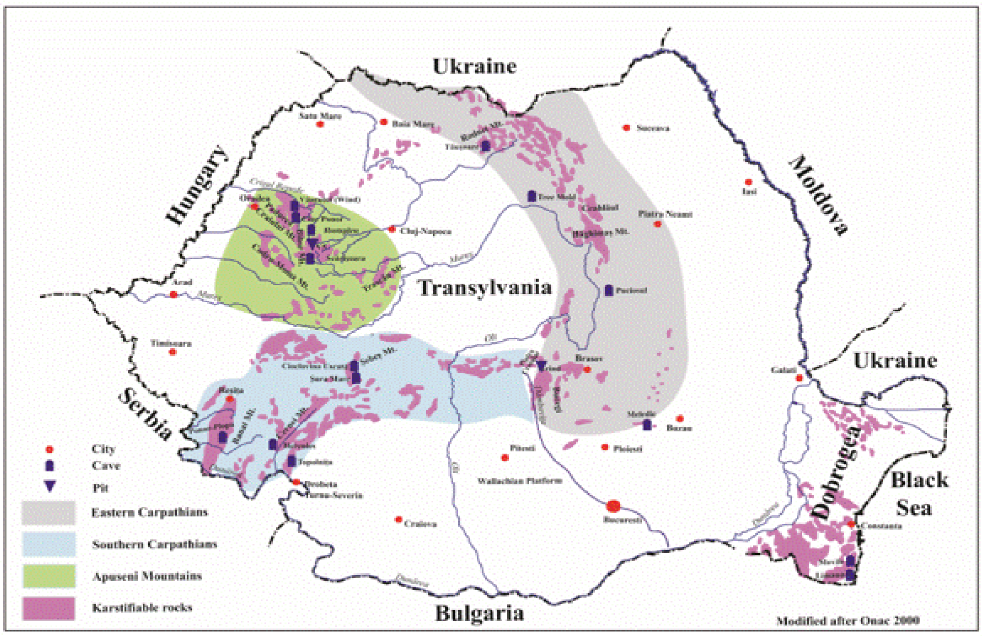


Figure 3. Karstifiable rocks of Romania (from Ponta and Ursu, 2017, with permission)

temperature ranges from −25°C in January to 31°C in July.

The first cave explorations and scientific research in Romania date back to 1,767, when J. Fridvaldszky, in his book dedicated to the mineralogy of the Principality of Transylvania published in Cluj, mentions six caves. In 1774, A. Nedeczky published in Vienna the description of the cave at

Fânaţe, followed by those published in 1778 by J. Benkő in Haarlem (Holland) and J.E. Fichtel (1780) in Nuremberg (Germany), which present the caves known until that date in Transylvania (Damm & Lascu, 2008). The nineteenth century is marked by an increase in exploratory activities driven by greater scientific interest devoted to cave exploration.

In 1836, I. Fekete published in Cluj the map of Mereşti Cave (Vârghişului Gorges), his initiative being followed by J. Wastler who in 1863 mapped Fânaţe, Scărişoara, Onceasa, Ferice and Meziad caves (Damm & Lascu, 2008). F. Posepny – one of the precursors of the hydrothermal theory in the genesis of caves in 1871 published the maps of the caves in the Băiţa Bihor area and Roediger in 1880 Igriţa's Cave map (Damm and Lascu, 2008). In 1887, G. Hazai mapped Măgura Cave and G. Téglás in 1891 published the maps of the caves in the Hunedoara region. A special mention must be given to Balázs Orbán who, in his Description of the Szekler Land (1868 – 1873) presents geological, geographical, archaeological and historical aspects related to the caves in the region. The leading work of the nineteenth century, however, is undoubtedly the study carried out by the famous Austrian geographer Adolf Schmidl: Das Bihargebirge an der Grenze von Ungarn und Siebenburgen published in 1863 in Vienna. The material presented in the book was obtained between 1858 and 1862 during a large-scale multidisciplinary expedition, organized by the Vienna Academy of Sciences in the Bihor Mountains, Pădurea Craiului and Codru Moma.

As a result of these investigations, at the end of the nineteenth century, according to the inventory made by E.A. Bielz (1884), the number of caves in Transylvania was 81. Starting at the end of the nineteenth century, the touristic interest in caves increased substantially. Czárán Gyula (1903), a wealthy lawyer in love with nature, spends almost his entire fortune on exploring and developing show caves and opening new tourist tracks in the Bihor Mountains. In 1903 the Vadu Crişului Cave was explored, and subsequently opened for tourism (Czárán, 1905).

Beginning in 1920, when the Institute of Speleology" Emil Racoviţă" (ISER) was established in Cluj-Napoca, the collection of documents and maps related to the caves of Romania started, and a depository established. Between 1920 and 1956, over 300 caves were recorded, the majority of them being documented in the ISER's publications.

Shortly after 1956, when the ISER was reorganized, with offices in Bucharest (București) and Cluj-Napoca, the recreational caving movement began, the first grottos/caving clubs began their activities in late fifties and sixties in several major cities in Romania: Cluj-Napoca, Reşiţa, București, Arad, etc. In 1965, the map of Romanian Karst Areas was published by ISER, which included about 1,000 caves (Goran, 1981).

The first Catalogue of Romanian Caves was compiled by Marcian Bleahu and Ioan Povară in 1976, and recorded about 2,000 caves, including the early discoveries of the recreational cavers. In the same year, The Central Committee of Sportive Speleology (CCSS) was formed as a subsidiary of Romanian Federation for Tourism and Alpinism, which up to 1989 was the largest organization in Romania with about 500 members and 40 to 50 grottos/caving clubs. For almost 15 years, CCSS with ISER promoted speleology, organizing short courses/camps for caving/climbing technique (SRT), cave survey, biology, and cave photography, through the National School of Speleology. The main sponsor of caving activities between 1969 and 1989 was Biroul de Turism pentru Tineret/Youth Bureau for Tourism (BTT).

CCSS had its own publication (Buletin FRTA; later becoming Buletin Speologic) and several caving clubs published new discoveries and trip reports in their bulletins and newsletters. Between 1972 and 1994, CCSS (after 1994 Romanian Federation of Speleology) organized annual conventions (Speosport), and sponsored survey camps to validate the maps of the main Romanian caves. In 1994 Speosport became the National Congress of Speleology. As a result of these activities, in 1981, The Systematic Catalogue of Romanian Caves/Catalogul Sistematic al Peșterilor din Romania (Goran, 1981) was published and included data about 6,816 caves. By 1989, the number of caves discovered and surveyed reached 12,000. Based on the Romanian Federation of Speleology's (FRS) web page (www.frspeo.ro), the number of known caves today in Romania is 12,600. The database related to these caves is hosted by ISER (official depository); a copy was at CCSS/after 1994 FRS, and the grotto/caving club who made the discovery and survey held a third one.

After 1989, the caving activity decreased due to better opportunities to travel outside Romania, and many experienced cavers abandoned the activity. Permission to access the cave database was allowed to the author/s of the discovery, or by others with his/their permission. The new generation of cavers found it difficult to get permission to view the cave-related maps and documents, and the database became obsolete and restricted.

In these circumstances, the webpage www.speologie.org, was started, where with cavers contributions, a new database was generated and made available on the web. The web page follows the same structure as the catalogue designed by Cristian Goran in 1981. The discrepancy between the 8,645 records available on the website and the approximately 12,600 caves reported by the Romanian Federation of Speleology suggests either incomplete data transfer or the presence of duplicate records.

Geology

Romania consists of four major geological areas: The Eastern Carpathians (Carpaţii Orientali), The Southern Carpathians (Carpaţii Meridionali), Apuseni Mountains, and Dobrogea. The Carpathians Mountains arcs have been shaped around an old rigid central structure in the alpine cycle.

The Eastern Carpathians with 1,062 caves are located between the Tisa River in the North and Dâmbovița River in the South and consist of numerous karstifiable rocks (limestones and dolomites of Triassic through Miocene age) scatters across this mountain range, overlaying a crystalline zone of Paleozoic and Precambrian age, and a flysch zone (Mesozoic rocks). The longest caves (e.g. Tăuşoare) in Eastern Carpathians are located in the Rodnei Mountains and are developed in Eocene (Priabonian) limestones.

Miocene salt deposits located at the south end host a unique karst landscape, with sinkholes and closed depressions (Ponta, 1984-1985). Neogene volcanoes exist in the central part of the Eastern Carpathians, contain tree-mold caves, lava caverns with opal, and others formed by the underground erosion of tufa layers of cemented agglomerates (Naum & Butnariu, 1967).

Dâmbovița River in the East, the Danube River in the West, and Mureș River and Transylvania in the North, defines the Southern Carpathians with 4,131 caves. The Southern Carpathians consists of three structural units: the Danubian terrane, the Severin nape, and the Getic terrane. The Danubian and Getic terranes consist of Mesozoic rocks that overlie Paleozoic and Precambrian sedimentary and crystalline rocks (Burchfiel et al., 1974). The majority of these caves are located in Jurassic-Cretaceous limestones. One of the longest underground streams in the country (Şura Mare) (Ponta, 1991) with a large bat colony, and a cave rich in minerals (Cioclovina Uscată) (Onac, 2000) was identified in this area. Ardealite (name comes from Ardeal, another name used for Transylvania) is a phosphate mineral found in Cioclovina Uscată and described for the first time by Halla in 1931.

In the Jurassic and Cretaceous limestones of Banat, karst platforms developed, with numerous caves and potholes. In one of the caves, Peștera cu Oase/Bones Cave, one of the oldest remains of a modern human (c. 40 ka) that shows evidence of admixture with Neandertalians was found (Trinkaus et al., 2013).

Hydrothermal karst is present within the Cerna Valley in southwestern Romania (e.g. Hercules Cave) in the Jurassic and Cretaceous limestone with air temperatures as high as 40°C, due to the presence of thermal water flowing through the caves (Povară, 2012).

The Apuseni Mountains with 3,234 caves are located between Mureș River in the south and Crișul Repede River in the North. Most of the limestones are in the northern Apuseni Mountains, which consist of Mesozoic sedimentary rocks overlying Paleozoic and Precambrian sedimentary and metamorphic rocks. The longest caves in the country (Wind/Vântului, Humpleu caves, and Ciur Ponor) (Ponta et al., 1991), the second deepest pothole (V5 Pit), and biggest perennial ice cave in Romania (Scărişoara) are located in these mountains. In Humpleu Cave 80 cm long single crystals were found, and in Valea Rea Cave 37 minerals were identified. In Ciur Izbuc Cave, about 400 footprints in mud, several thousand years old, and in Vârtop Cave three footprints preserved in a calcite crust were found, dated 62 ka (Onac et al., 2005). Also, the Bears Cave (Peștera Urşilor) is known for several cave bear skeletons.

The Dobrogea area comprises a group of low mountains, where 99 caves were identified. Upper Jurassic and Barremian limestones and dolomites, Senonian chalk and Sarmatian limestones occur in this area. Here is the location of Movile cave with its groundwater ecosystem rich in hydrogen sulfide and carbon dioxide, and Limanu cave with 4,000 meters of passages formed by solutioning with several man-made enlarged passages.

Karst

The Romanian karst landscape was generated in the Quaternary and can be classified into three categories, characterized by the hydrodynamic conditions of the karst aquifers and the relationship between karst aquifer and land surface (Ponta, 1998):

1. Deep Karst type features (paleokarst) occur in the sedimentary rocks underlying non-soluble bedrock and overlain by aquicludes or aquitard deposits. These confined aquifers are typical to the Wallachian Platform. The Carbonate Deposits of Malm-Barremian Ages are 1,500 m thick and can be found at a depth ranging between 1,800 m to 2,000 m in the Wallachian Platform (Ponta, 1998).

2. Shallow Karst type features are in sedimentary rocks overlain by unconsolidated sediments. The thickness of the overburden range between 10 m to 50 m. This type of karst has the greatest extension in Dobrogea, where the overburden is formed mainly by loess (Ponta, 1998).

3. Bare/exposed karst occupies approximately 5,500 km^2 (Onac, 2000) on the Romanian territory (approx. 2.3% of the Romania's surface). The most karstified deposits belong to the Jurassic-Cretaceous sedimentary cycle. In the Southern Carpathians, the largest exposed carbonates region is Banat (800 km2) and the most karstified area is in the Bihor Mountains (Apuseni Mountains) (Bleahu & Rusu, 1965).

Recrystallized Paleozoic carbonate deposits represent about 16% of the total bare karst. The Mesozoic deposits belong to two sedimentary cycles (Triassic 17. 8% and Jurassic-Cretaceous 47.3%), and the Neogene deposits to a third cycle (Eocene, Tortonian and Sarmatian 16.8%) (Bleahu & Rusu, 1965).

Based on the geomorphological and structural aspects, there are three types of karst landscape specific to the Romania's territory:

1. Plateau type karst is characterized by large dolomite or limestone plateaus with surface karstic features like karrens (lapiés), dolines (sinkholes), closed depressions, dry valley and streams with elevation range between 600 m to 2000 m and covers areas between 20 km2 and 120 km2. The thickness of the carbonate deposits ranges between 200 m and 600 m and alternates with non-carbonate rocks. The most important plateaus are in the Bihor, Pădurea Craiului, Codru Moma, Sebeș or Banat Mountains (Bleahu, 1972).

2. Bar/Ridge type karst is ridges derived from carbonate deposits approx. 200 m thick, which dip at over 450. As in the previous case, generally the carbonate rocks alternate with non-soluble rocks. Due to the differentiated erosion processes very prominent limestones-dolomite ridges appear. The strike or these is controlled by longitudinal faults with regional extension and are cut by transverse faults, on which the karst aquifer is opened and emerges to the surface through springs. The most representatives' ridges are in the Hăghimaş, Piatra Craiului, Vânturariţa, and Trascău massifs (Bleahu & Rusu, 1965).

3. Isolated massifs are an intermediate type between the previous two, being less extended plateaus such as the Ceahlău or the Dâmbău in the Metaliferi Mountains or olistoliths on the limestones in the Piatra Mare and Bucegi Mountains (Bleahu & Rusu, 1965).

Results and Discussion

While the extension of karstifiable rocks represents only 5,500 km^2 scattered across Romania, a diverse range of caves are present:

Limestones and Dolomite caves

From the total of 8,645 caves, 97% are developed in limestones and dolomites rocks, only 3% being hosted in other rocks. The largest numbers of caves are located in Bihor Mountains (1160), which represents 13.4%, followed by Pădurea Craiului with 1059 (12.2%) and Vâlcan Mountains 813 (9.4%). The total length of surveyed passages is 1,042 km. There are 164 caves over 1 km long, 110 caves with vertical development higher than 100 m, 24 caves in salt, and 132 caves protected by law (Moldovan, 2019). The longest cave is Peștera Vântului (approx. 50 km) and the deepest one is Avenul din Colții Grindului with -815 m. 80 caves are totally submerged being accessible only by divers. The deepest sump is in Izbândiș Cave (-129 m), and the longest one is Sifonul Negru (Black Sump) in Isverna cave, almost 700 m long. In the database, elevation of the entrances is known for 4,408 caves, of which 3,697 ranges between 300 to 1200 m. The intervals with the highest number of caves (at 100 m increments) are 400-500 with 718 caves, followed by 500-600 interval, with 574 caves, and 1,100-1,200 m interval with 448 caves.

Evaporates/salt karst

The karst formed on evaporite rocks represents 5% of the Romania's bare type karst and is in the lowland hills of Eastern Carpathians. The largest zone is Săreni - Trestioara situated between Slănic Valley, Sării Valley and Meledic Valley, known under the name of Meledic plateau. The average altitude of the area is 600 m, and presents caves, deep valleys, karren and sinkholes (50 m in diameters) (Ponta, 1998).

Volcanic caves

Puciosul cave (Peștera din Muntele Puturosul) located in the central part of the Eastern Carpathians is 14 m long, with sulfur deposits on the walls as a result of hydrogen sulfide and carbon dioxide released by volcanic activity. Carbon dioxide (CO2) is heavier than air, so operating below the CO2 /air interface is fatal. Tree Mold caves are located on the upstream section of Mureș River, in the Toplița-Deda gorges. The caves were formed when the Călimani - Gurghiu volcano was active, and its lava flew out and covered the forest, trapping trees. In time, the trees were washed away, leaving behind the tree mold/shape caves (Moreh, 2009).

Thermal Caves

Thermo-mineral karst (thermal waters) is present in the Băile Herculane, Mangalia and Geoagiu areas (Bleahu and Rusu, 1965). The largest hydrothermal karst reservoir is in Băile Herculane within the Cerna Valley, in southwestern Romania, where the longest thermal water cave, Hercules (82 m long) is traversed by a stream with temperatures as high as 28°C to 30°C.

Ice Caves

Several ice caves are known in Romania as: Focul Viu, Avenul cu Zăpadă, and Scărişoara. Scărişoara cave previously known to host a 3,000 to 5,000 years old deposit of perennial ice with a volume estimated at 100,000 cubic meters (Onac et al., 2010). Perşoiu in 2017 and 2018, determined that the ice block is over 10,000 years, exceeding 100,000 cubic meters in volume and an average thickness of 22 meters, being one of the largest known underground ice bodies worldwide and a unique paleoclimatic archive (Perşoiu et al., 2017, Perşoiu, 2018).

Mineralogy

Minerals were identified in several caves in Romania. Cioclovina Uscată and Peștera din Valea Rea Cave are characterized by remarkable mineral diversity. Ardealite (name comes from Ardeal, which is another name for Transylvania) is a phosphate mineral found in Cioclovina Uscată and described for the first time by Halla in 1931.

Sulfuric Acid/Hypogene Speleogenesis Caves

Movile Cave (Peștera Movile) is known for its groundwater ecosystem rich in hydrogen sulfide and carbon dioxide. Life in the cave is sustained by microbial mats (bacteria) on the cave walls and the surface of pools, based on chemosynthesis (Sarbu et al., 1996).

Historical and Anthropological Caves

Paintings were found in Cuciulat and Coliboaia Caves. Marin Cârciumaru estimated that the Cuciulat cave paintings were completed in the Upper Paleolithic, about 12,000 years ago (Cârciumaru & Bitiri, 1983). The oldest cave paintings in Central Europe, estimated at between 23 000 and 35 000 BP (Gravettian or Aurignacian) have been discovered by a team of Romanian speleologists in the Coliboaia Cave, Bihor Mountains (Clottes et al., 2012). In Peștera cu Oase/Bones Cave, one of the oldest remains of a modern human (c. 40 ka) that shows evidence of admixture with Neandertalians was found (Trinkaus et al., 2013). In Ciur Izbuc cave about 400 footprints in mud several thousand years old, and in Vârtop Cave three footprints preserved in a calcite crust were found.

Biospeleology

Romania is one of the best-investigated European countries for biospeleology. In 1920 Emil Racoviţă founded world's first Institute of Speleology in Cluj-Napoca. Romania has a rich cave fauna with many endemic elements. There are 31 bat species found in seven caves that are considered shelters of major importance (Coroiu, 2017). Bone remains belonging to the Upper Pleistocene cave bear (Ursus spelaeus) were found in numerous caves, as Peştera de la Vadul Crişului or The Bears Cave (Peştera Urşilor).

The longest caves in Romania

1. Peștera Vântului	50,000 m
2. Peștera Mare din Valea Firii (Sistemul Humpleu)	36,600 m
3. Sistemul Vărăşoaia (V5-V24)	30,500 m
4. Peștera din Pârâul Hodobanei	22,142 m
5. Peștera Topolnița	20,500 m
6. Sistemul Ciur Ponor-Topliţa de Roșia	20,150 m
7. Peștera din Valea Rea	16,357 m
8. Sistemul Zăpodie-Peștera Neagră	12,048 m
9. Peștera Șura Mare	11,694 m
10. Peștera Polovragi	10,350 m

The deepest caves in Romania

1. Avenul de sub Colţii Grindului	815 m
2. Sistemul Vărăşoaia (V5-V24)	690 m
3. Peștera de la Izvorul Tăuşoarelor	461 m
4. Peștera Şura Mare	425 m
5. Avenul din Dealul Secăturii	390 m
6. Peștera din Valea Rea	372 m
7. Avenul din Stanul Foncii	339 m
8. Peștera Mare din Valea Firii (Sistemul Humpleu)	314 m
9. Peștera Jgheabul lui Zalion	303 m
10. Avenul de Rezervă	300 m

The stories of these explorations are extensively presented in a book series entitled ″10,000″, the first volume being published in 2019 (Bleahu et al.2019), followed momentarily by volumes 2 and 3 (Aldica et. al, 2021; Perlik et al., 2023). A collection of scientific papers can be found in ″Caves and Karst Systems of Romania″ edited by Ponta and Onac and publish in Springer's series ″Caves and Karst Systems of the World″.

Conclusion

The Conclusion section presents the outcome of the work by interpreting the findings at a higher level of abstraction than the Discussion and by relating these findings to the motivation stated in the Introduction. Papers without conclusion won't be accepted.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

All authors provided critical feedback and helped shape the research, analysis and manuscript.

Acknowledgements

These investigation through 1989 were partially funded by The Central Committee of Sportive Speleology (CCSS), a subsidiary of Romanian Federation for Tourism and Alpinism, and Biroul de Turism pentru Tineret/Youth Bureau for Tourism (BTT). Acknowledgment is made to hundreds of cavers and scientists who graciously dedicated their time and money to provided information on caves, springs and other significant karst-related data. Over the years more than 12,000 caves have been discovered, surveyed, and registered with the National Cave Cadaster of Romania, maintained by the "Emil Racoviță" Institute of Speleology (ISER). The authors express their sincere gratitude to all cavers and scientists whose contributions have greatly advanced the exploration and documentation of Romanian karst.

ORCID iD

Gheorghe M.L. Ponta [https://orcid.org/ 0000-0001-5067-3201](https://orcid.org/0000-0001-5067-3201)

References

Aldica, G. V., Perlik, R. A., Cazan, G., Pop, R., & Bușu, L. (2021). 10.000 (Vol. 2). Editura Art Soleil.

Benkő, J. (1778). Transsilvania sive Magnus Transsilvaniae Principatus olim Dacia Mediterranea dictus. In Beschreibung einiger Berge und Höhlen in Burzenland und Zekelland. Siebenbürgische Quartalschrift.

Bielz, E. A. (1884). Beitrag zur Höhlenkunde Siebenbürgens.

Bleahu, M. (1972). Karst of Rumania. In M. Herak & V. T. Stringfield (Eds.), Karst: Important karst regions of the Northern Hemisphere (pp. 341–353). Elsevier.

Bleahu, M., Perlik, R. A., Aldica, G. V., Bușu, L., & Cazan, G. (2019). 10.000 (Vol. 1). Editura Art Soleil.

Bleahu, M., & Rusu, T. (1965). Carstul din Romania. O scurtă privire de ansamblu. Lucrările Institutului de Speologie Emil Racoviță, 4.

Burchfiel, B. C., Bleahu, M., Borcoș, M., Patrulius, D., & Săndulescu, M. (1974). Geology of Romania. Geological Society of America Special Papers, 158.

Cârciumaru, M., & Bitiri, M. (1983). Peintures rupestres de la grotte Cuciulat (Roumanie). Bulletin de la Société Préhistorique Française, 80(3), 94–96.

Clottes, J., Besesek, M., Gely, B., Ghemiș, C., Kenesz, M., Lascu, V. T., Meyssonnier, M., Philippe, M., Plichon, V., Prud'homme, F., Radu, V. A., & Rus, T. (2012). Découverte d'une nouvelle grotte ornée paléolithique en Roumanie, dans le département du Bihor. In J. Clottes (Ed.), L'art pléistocène dans le monde: Actes du Congrès IFRAO, Tarascon-sur-Ariège, septembre 2010 – Symposium "Art pléistocène en Europe" (pp. 513–528).

Coroiu, I. (2017). Chiropteran fauna in the caves of Romania (Unpublished manuscript).

Czárán, G. (1903). Kalauz a biharfüredi kirándulásokra. Süssmann Lázár Nyomda.

Czárán, G. (1905). Cseppkőbarlangok Rév környékén. A Révi Zichy cseppkőbarlang. Erdély, (1–2).

Damm, P., & Lascu, V. (2008). Speologia explorativă în România. https://www.frspeo.ro/speologia-explorativa-in-romania

von Fichtel, J. E. (1780). Geschichte des Steinsalzes und der Steinsalzgruben im Großfürstenthum Siebenbürgen (Vol. 2). Raspe.

Fridvaldszky, J. (1767). Minero-logia magni Principatus Transilvaniae seu metalla, semi-metalla, sulphura, salia, lapides, & aquae. Academicis Societatis Jesu.

Goran, C. (1981). Catalogul sistematic al peșterilor din România. Institutul de Speologie Emil Racoviță.

Halla, F. (1931). Isomorphe Beziehungen und Doppelsalzbildung zwischen Gips und Brushit. Zeitschrift für Kristallographie-Crystalline Materials, 80(1–6), 349–352.

Hazay, G. (1887). A József főherczeg barlang a Biharban. Természettudományi Közlöny, 19, 188–247.

Moldovan, O. (2019). Cave protection in Romania. In G. M. L. Ponta & B. P. Onac (Eds.), Cave and karst systems of Romania (pp. 537–542). Springer.

Moreh, K. (2009). Peșteri de mulaj. Speomond, 9, 44–48.

Naum, T., & Butnariu, E. (1967). Le vulkano-karst de Călimani (Carpathes roumaines). Annales de Spéléologie, 22, 727–755.

Nedeczky, A. (1774). Funacza Pestyere seu antri funacza dicti historico-physica relatio. Johann Thomas Trattner.

Onac, B. P. (2000). Geologia regiunilor carstice. Editura Didactică și Pedagogică.

Onac, B. P., Cocean, P., & Ponta, G. (1996). Une vue globale sur le karst roumain. Kras i Speleologia, 8(17), 105–112.

Onac, B. P., Racoviță, G., & Brad, T. (2010). Atlasul peșterilor din Munții Apuseni: Bazinul Arieșului Mare. University of South Florida Libraries.

Onac, B. P., Viehmann, I., Lundberg, J., Lauritzen, S. E., Stringer, C., & Popiță, V. (2005). U–Th ages constraining the Neanderthal footprint at Vârtop Cave, Romania. Quaternary Science Reviews, 24(10–11), 1151–1157.

Orbán, B. (1871). A Székelyföld leírása történelmi, régészeti, természetrajzi s népismei szempontból (Vol. 2). Helikon Kiadó.

Perlik, R. A., Cazan, G., Aldica, G. V., Minghiraș, T., Pop, R., & Bușu, L. (2023). 10.000 (Vol. 3). Editura Art Soleil.

Perșoiu, A. (2018). Ice caves climate. In A. Perșoiu & S. E. Lauritzen (Eds.), Ice caves (pp. 21–32). Elsevier. https://doi.org/10.1016/B978-0-12-811739-2.00003-6

Perșoiu, A., Onac, B. P., Wynn, J. G., Blaauw, M., Ioniță, M., & Hansson, M. (2017). Holocene winter climate variability in Central and Eastern Europe. Scientific Reports, 7, 1196.

Ponta, G. (1984–1985). The evaporite karst of Rumania. Le Grotte d'Italia, 12(4), 407–415.

Ponta, G. (1991). New tracing experiences in the Sebeș Mountains, Rumania. In Proceedings of the International Conference on Environmental Changes in Karst Areas (pp. 195–204). Università di Padova.

Ponta, G. (1998). Karst of Romania. In Global Karst Correlation (IGCP 299) (pp. 193–207).

Ponta, G. M., & Onac, B. P. (Eds.). (2018). Cave and karst systems of Romania. Springer.

Ponta, G. M., & Ursu, V. (2017). Highlights of Romanian caves and karst. In Proceedings of the 17th International Congress of Speleology (Vol. 2, pp. 74–78).

Ponta, G., Terteleac, N., & Gaspar, E. (1991). Three karstic systems (Roșia, Toplița de Roșia and Vadul Crișului) in the Pădurea Craiului Mountains, Rumania. Theoretical and Applied Karstology, 4, 129–142.

Posepny, F. (1871). Studien aus dem Salinargebiete Siebenbürgens. Jahrbuch der Kaiserlich-Königlichen Geologischen Reichsanstalt, 21, 123–186.

Povară, I. (2012). Valea Cernei: Morfologie, hidrologie, ape termominerale. Editura AGIR.

Sârbu, S. M., Kane, T. C., & Kinkle, B. K. (1996). A chemoautotrophically based cave ecosystem. Science, 272(5270), 1953–1955.

Schmidl, A. (1863). Das Bihar-Gebirge an der Grenze von Ungarn und Siebenbürgen. Förster & Bartelmus.

Téglás, G. (1891). Újabb barlangok az erdélyi érczhegység övéből és a Fejér-Körös Hunyad megyei völgyszakaszáról. Mathematikai és Természettudományi Közlemények, 24(5), 303–338.

Trinkaus, E., Constantin, S., & Zilhão, J. (Eds.). (2013). Life and death at the Peștera cu Oase: A setting for modern human emergence in Europe. Oxford University Press.

Transformation of Global Ecopolitical Terminology and Prospects for Its Integration into National Policy: The Case of Georgia

Tamar Chichinadze
[1] Vakhushti Bagrationi Institute of Geography, Ivan Javakhishvili Tbilisi State University, Tbilisi, Georgia
* Corresponding author: tamar.chichinadze@tsu.ge

Georgian Geographical Journal, 2026, 6(1) 67-74

DOI:
https://journals.4science.ge/index.php/GGJ

Citation: Chichinadze, T. Transformation of Global Ecopolitical Terminology and Prospects for Its Integration into National Policy: The Case of Georgia. *Georgian Geographical Journal* 2026, 6(1), 67-74. https://doi.org/10.52340/ggj.2026.06.01.09

Abstract

In recent years, environmental governance and political geography have undergone significant conceptual transformations at global, academic, and policy levels. Current environmental discourse increasingly emphasises integrative approaches such as Nature-Positive Policies (NP), Environmental Justice (EJ), and Nature-Based Solutions (NBS). Although these concepts emerged within distinct theoretical and institutional contexts, they are increasingly interconnected within international environmental governance and sustainability planning. Collectively, they reflect a transition from reactive environmental management toward proactive strategies focused on ecosystem restoration, climate resilience, participatory governance, and socially equitable development. This paper examines the evolution of these emerging ecopolitical concepts, their theoretical and practical significance, and the prospects for their incorporation into Georgia's environmental governance framework. The study employs a qualitative, conceptual, and comparative approach, drawing on academic literature, international environmental frameworks, and selected national policy documents. Particular attention is given to the adaptation and localisation of global environmental paradigms within the Georgian context. The research demonstrates that integrating global ecopolitical terminology into national policy is not merely a linguistic or administrative process, but also requires institutional adaptation, improved spatial planning mechanisms, stronger participatory governance, and the incorporation of social justice principles into environmental decision-making. These issues are particularly relevant for Georgia in relation to geopark development, biodiversity conservation, climate adaptation, and sustainable regional planning. The paper argues that integrating NP, EJ, and NBS approaches can strengthen resilient and inclusive environmental governance in Georgia while improving alignment with contemporary international environmental strategies. By analysing the interpretation and localisation of global ecopolitical concepts, the study contributes to broader discussions concerning the relationship between international environmental discourse and national policy transformation.

Keywords: Nature-positive policy; Environmental justice; Nature-based solutions (NBS); Ecopolitical terminology; Ecological governance

Introduction

Since the beginning of the twenty-first century, global environmental policy shifted from traditional, reactive governance focused on pollution mitigation toward proactive approaches emphasising ecosystem restoration, climate resilience, and socio-environmental sustainability. Among these emerging paradigms, Nature-Positive (NP) policies actively promote the restoration and regeneration of degraded ecosystems rather than merely minimising ecological losses. Concurrently, Environmental Justice (EJ) ensures the equitable distribution of environmental benefits and public participation in decision-making (Schlosberg, 2007). Complementing these frameworks, Nature-Based Solutions

(NBS) strategically leverage natural ecosystem processes to address interconnected climate and societal challenges.

The institutionalisation of NP, EJ, and NBS reflects a growing consensus that modern ecological governance extends beyond purely technical or administrative mandates. Instead, it requires interdisciplinary strategies capable of integrating ecological integrity with social equity and robust spatial planning. This conceptual evolution carries profound implications for transitional economies such as Georgia, where high ecological vulnerability, regional development demands, and local community needs are deeply intertwined.

Adapting global environmental concepts to the Georgian context specifically across its diverse mountain ecosystems, protected areas, and climate-sensitive transboundary zones like the Alazani Valley cannot be treated as a tokenistic administrative exercise. Rather, it demands the systematic harmonisation of national policy mechanisms, institutional capacity, and meaningful grassroots public participation.

This study examines the conceptual evolution of NP, EJ, and NBS, evaluating both the opportunities and barriers for their structural incorporation into Georgia's environmental policy framework. Using a qualitative, conceptual, and comparative approach, the research evaluates international frameworks against Georgia's domestic environmental strategies.

Building upon recent insights regarding the convergence of ecological governance, spatial strategy, and protected areas policy in Georgia (Chichinadze & Tsiklauri, 2025), this paper explores how these global approaches can be practically localised. Ultimately, this study demonstrates that incorporating these interconnected frameworks can transition Georgia toward a more resilient, inclusive, and internationally aligned environmental governance model, effectively bridging the gap between global ecopolitical discourse and national policy execution.

Literature Review and Conceptual Framework

Nature-Positive Policy (NP)

Nature-Positive Policy (NP) has become one of the leading approaches in contemporary environmental governance. It represents a significant shift from reactive environmental strategies focused primarily on damage limitation toward proactive approaches aimed at restoring, regenerating, and enhancing natural systems. Since 2020, NP has gained increasing international attention through initiatives such as the UN Convention on Biological Diversity (CBD) and the European Union Biodiversity Strategy for 2030 (Convention on Biological Diversity, 2023). It is now widely recognised as a central framework for addressing biodiversity loss and promoting long-term socio-ecological sustainability.

At its core, NP is based on three main principles:

* Reducing pressures on ecosystems and preventing further environmental degradation;
* Restoring, rehabilitating, and reconnecting damaged ecological structures and functions;
* Promoting sustainable coexistence between human activities and natural systems through integrated governance approaches.

Numerous scholars emphasise that nature-positive approaches represent more than an environmental objective; they reflect a broader normative transformation in global ecopolitical thinking. Rather than viewing conservation solely as protection, these approaches emphasise ecological restoration and regeneration, aiming to achieve net positive environmental outcomes rather than simply minimising losses. This perspective requires systemic and landscape-level approaches that integrate biodiversity considerations into sectors such as agriculture, energy, infrastructure, and regional development. Consequently, NP approaches closely align with broader sustainability agendas, including the Sustainable Development Goals (SDGs) and climate adaptation strategies.

Within the European Union, nature-positive approaches have become important drivers of environmental policy innovation. The experiences of Germany, the Netherlands, and Scandinavian countries demonstrate how governments integrate nature-positive principles into biodiversity offset mechanisms, ecological compensation systems, green infrastructure planning, and nature-inclusive development strategies **(**European Commission, 2019**)**. These examples illustrate how ecological restoration objectives can be incorporated into legal and administrative systems, ensuring that development initiatives contribute to long-term environmental sustainability.

At the global level, nature-positive policies increasingly connect biodiversity conservation, climate governance, and environmental justice. International organisations emphasise that these approaches should not only restore ecosystems but also generate social benefits, ensure equitable access to environmental resources, and strengthen participatory governance mechanisms. In this regard, NP approaches align closely with rights-based environmental governance models by addressing the disproportionate environmental burdens faced by vulnerable communities while supporting ecological and economic resilience.

Despite their transformative potential, the literature also identifies several challenges associated with NP implementation. The broad scope of nature-positive policies may create conceptual ambiguity, allowing governments or private actors to adopt nature-positive language without producing meaningful ecological outcomes. Critics further argue that market-based mechanisms, including biodiversity offsets, may unintentionally justify environmental degradation if they are not accompanied by clear ecological standards and transparent monitoring systems.

The implementation of nature-positive policies is particularly challenging in countries with limited institutional capacity. Studies conducted in Southern and Eastern Europe highlight barriers such as insufficient ecological data, weak intersectoral coordination, limited financial resources, and low levels of public participation. These structural constraints complicate the embedding of NP principles into land-use planning, agricultural governance, and spatial development policies. Effective implementation, therefore, requires reliable biodiversity monitoring systems, long-term financial support, participatory governance mechanisms, and institutional reforms.

In summary, nature-positive policies represent both far-reaching opportunities and complex governance challenges. By combining ecological restoration, social equity, and cross-sectoral coordination, NP approaches create significant opportunities for sustainable development while simultaneously revealing the institutional, financial, and political barriers that states must overcome for effective implementation.

Environmental Justice (EJ)

Environmental Justice (EJ) is one of the cornerstone concepts in current environmental governance. At its core, EJ is based on the principle that all individuals, regardless of race, ethnicity, income, or place of residence, should have fair access to environmental benefits and an equal opportunity to participate in decision-making processes that affect their environment (Schlosberg, 2007). The concept gained prominence in the United States in the late 1980s, when social movements drew attention to the disproportionate exposure of marginalised communities to industrial pollution, toxic waste, and other environmental hazards. These movements laid the foundation for EJ as a framework that integrates environmental protection with social equity and human rights (Bullard, 1990).

EJ is commonly understood through three interrelated dimensions:

* Distributional justice: Concerns the fair allocation of environmental benefits and burdens, ensuring that no social group bears a disproportionate share of environmental harm.

* Procedural justice: Emphasises inclusive and transparent decision-making processes, guaranteeing that all stakeholders have a meaningful voice in environmental governance, policy development, and impact assessment.

* Recognition justice focuses on acknowledging specific vulnerabilities, cultural identities, and historical disadvantages of different communities (Schlosberg, 2007; Pellow, 2018). It aims to address these challenges effectively.

Together, these dimensions form a comprehensive framework that links ecological protection with social equity and democratic governance.

Globally, EJ principles are increasingly integrated into environmental policy and governance structures. Institutions such as the United Nations Environment Programme (UNEP) and the European Union have incorporated EJ considerations into environmental initiatives, promoting public participation, accountability, and equitable distribution of environmental benefits. For instance, EU policy frameworks emphasise public engagement, consultation processes, and inclusive governance mechanisms that reflect both procedural and recognition dimensions of environmental justice (UNECE, 2014). When effectively implemented, EJ-oriented initiatives are associated with improved environmental outcomes, including better air and water quality, as well as strengthened community resilience through local empowerment and capacity-building. In this way, environmental justice contributes simultaneously to ecological sustainability and human development.

However, implementing EJ principles is challenging, especially in countries with centralised governance, limited public participation, or weak institutions. Research shows that procedural mechanisms may formally exist but often do not ensure meaningful community engagement. This results in symbolic or superficial application of justice principles (Agyeman et al., 2016). Also, insufficient ecological and socio-economic data hinder accurate identification of vulnerable populations and assessment of equitable distribution of environmental risks and benefits. These limitations show that effective environmental justice needs not only normative commitment but also robust institutions, reliable data systems, legal frameworks, and public awareness.

Furthermore, scholars emphasise that EJ should not be treated as an isolated framework; rather, it must be integrated into broader environmental strategies, including climate adaptation, biodiversity conservation, and nature-based solutions. Without careful contextual adaptation, global EJ frameworks may unintentionally reproduce inequalities or fail to empower the very communities they aim to protect (Schlosberg, 2013). This highlights the importance of governance approaches that combine top-down policy design with bottom-up participatory processes.

In summary, Environmental Justice provides a powerful analytical lens for understanding the interconnections between ecological systems and social structures. By emphasising fair distribution, inclusive participation, and recognition of vulnerable groups, EJ offers a multidimensional foundation for environmental governance. Although significant challenges remain, particularly in contexts with limited institutional capacity, carefully designed and context-sensitive implementation of EJ principles can enhance environmental outcomes, strengthen community resilience, and support more equitable and sustainable governance at local, national, and global scales.

Nature-Based Solutions (NBS)

Nature-Based Solutions (NBS) have become a central approach in current environmental governance, emphasising the use of natural processes and ecosystem functions to address societal and environmental challenges. These include climate change adaptation, disaster risk reduction, biodiversity conservation, and sustainable development (Cohen-Shacham et al., 2016). Unlike traditional engineering-based approaches, NBS build upon the inherent capacities of ecosystems to generate multiple ecological, social, and economic benefits simultaneously. International organisations such as the European Union, the United Nations, and the International Union for Conservation of Nature (IUCN) increasingly support NBS as an important mechanism for achieving global sustainability goals, including the SDGs and the objectives of the Paris Climate Agreement (IUCN, 2020).

Several characteristics define NBS approaches:

* Solution-oriented: Designed to generate practical outcomes such as flood mitigation, soil stabilisation, carbon sequestration, ecosystem restoration, and urban environmental improvement.
* Context-specific: Must be adapted to local ecological, social, and cultural conditions.
* Multifunctional: Capable of simultaneously supporting biodiversity conservation, climate resilience, and social well-being (Eggermont et al., 2015).

These characteristics make NBS particularly relevant for integrated landscape management and for countries attempting to balance environmental protection with development priorities.

Nature-based solutions are increasingly implemented across different regions of the world. In Europe, initiatives such as wetland restoration in the Netherlands, urban green infrastructure projects in Germany, and forest restoration programs in Spain demonstrate how NBS can combine ecological restoration with economic and social benefits (Kabisch et al., 2017). At the international policy level, the IUCN categorises NBS into several broad areas, including ecosystem restoration, ecosystem-based management, and climate adaptation measures, which help guide both public and private environmental investments (IUCN, 2020). Research further demonstrates that carefully planned NBS initiatives can reduce climate vulnerability, strengthen ecosystem services, and improve social resilience (UNEP, 2021).

Despite these advantages, implementing NBS remains challenging. Effective implementation requires strong scientific expertise, reliable ecological and socio-economic data, coordinated multi-level governance, and sustainable financial mechanisms. Critics argue that some NBS initiatives are implemented superficially and function primarily as symbolic “green” interventions without generating measurable ecological and social benefits (Cohen-Shacham et al., 2016). Similarly, market-oriented mechanisms, such as ecosystem-based carbon offset projects, may prioritise economic interests over ecological integrity unless supported by transparent governance and effective monitoring systems.

Georgia has considerable potential for implementing NBS due to its ecological diversity, including mountain landscapes, river valleys, wetlands, and coastal ecosystems. Measures such as afforestation, wetland restoration, riverbank stabilisation, and urban green infrastructure development may help address climate risks, strengthen biodiversity conservation, and provide socio-economic benefits to local communities. However, successful implementation depends on integrating NBS into national environmental policies, geopark management frameworks, spatial planning systems, and climate adaptation strategies. The effectiveness of NBS in Georgia is also closely connected to principles of environmental justice and nature-positive governance.

In conclusion, Nature-Based Solutions represent a transformative framework for sustainable environmental governance. By combining ecosystem restoration, climate adaptation, and socio-economic benefits, NBS offer multidimensional approaches that connect global sustainability objectives with local environmental realities. However, their long-term effectiveness depends on careful planning and implementation, inclusive governance, adequate financing, scientific monitoring, and strong institutional support to ensure both ecological integrity and social inclusion.

Methodology

This research applies an interdisciplinary, qualitative, conceptual, and comparative methodology to examine the transformation of emerging global ecopolitical terminology and evaluate the prospects for its structural embedding into national environmental governance in Georgia. The study specifically unpacks three interconnected, paradigm-shifting frameworks: Nature-Positive Policies (NP), Environmental Justice (EJ), and Nature-Based Solutions (NBS).

To ensure analytical rigour, the research design is structured into three consecutive operational phases:

* Phase 1: Conceptual Mapping and Discursive Evaluation. This stage involves a systematic review of international academic literature and institutional frameworks to trace the theoretical origins, normative shifts, and operational criteria of NP, EJ, and NBS. Material for this phase was sourced from peer-reviewed scholarly publications, as well as landmark strategy papers developed by the European Union (EU), the United Nations Environment Programme (UNEP), and the International Union for Conservation of Nature (IUCN).

* Phase 2: National Policy and Legal Contextualization. This stage critically reviews the current landscape of Georgia’s domestic environmental policies. Rather than assessing statistical compliance, this phase utilises qualitative content analysis to identify conceptual gaps, institutional readiness, and the degree to which global ecopolitical terms are currently codified or absent within national strategic planning.

* Phase 3: Case-Specific Synthesis and Localisation. The final phase explores the practical application of the integrated theoretical framework within specific geographical and socio-ecological contexts in Georgia, examining targeted initiatives such as geopark development, protected areas management, and transboundary climate adaptation.

Georgia serves as an ideal case study for this analysis due to its complex geopolitical position, high vulnerability to climate change, and ongoing environmental sector reforms driven by international obligations. Building on previous analyses regarding the intersections of protected areas policy, ecological governance, and spatial strategies within the country (Chichinadze & Tsiklauri, 2025), this study expands the analytical scope. It extends beyond a purely spatial-geopolitical perspective to evaluate how emerging global concepts can be operationally adapted to Georgia's localised geographical, administrative, and socio-cultural realities. Particular emphasis is placed on ecologically sensitive zones, including mountain ecosystems, protected areas, and key transboundary regions such as the Alazani Valley.

The primary qualitative data for the policy review comprises a selected corpus of national strategic documents, including Georgia's National Environmental Action Programme (NEAP) (Ministry of Environmental Protection and Agriculture of Georgia, 2018), the National Biodiversity Strategy and Action Plan (NBSAP) (Ministry of Environmental Protection and Agriculture of Georgia, 2014) , and emerging regional spatial and climate adaptation guidelines.

Discussions

The integration of global ecopolitical concepts, specifically Nature-Positive Policies (NP), Environmental Justice (EJ), and Nature-Based Solutions (NBS) into Georgia’s environmental governance is not merely an exercise in academic alignment but a strategic imperative for sustainable regional development. Evaluating these frameworks against Georgia’s current domestic policy instruments reveals critical implementation pathways, existing institutional gaps, and significant opportunities for localisation.

Aligning the National Biodiversity Strategy and Action Plan (NBSAP) with Nature-Positive Paradigms

Georgia, recognised as a global biodiversity hotspot, has historically anchored its ecological governance in traditional conservation models via the National Biodiversity Strategy and Action Plan (NBSAP). However, current national strategies largely adhere to a reactive, defensive posture focused primarily on the mitigation of ecological degradation and the strict protection of designated areas.

Integrating the Nature-Positive (NP) framework into the upcoming iterations of the NBSAP facilitates a paradigm shift from passive protection to active ecosystem restoration and regeneration. This shift is crucial for managing current initiatives like geopark development and protected areas network expansions. Embracing an NP framework requires that spatial development in sensitive zones- such as the semi-arid landscapes of Kakheti and the volcanic plateaus of Javakheti- does not simply aim for "zero net loss" of biodiversity but actively guarantees net-positive ecological outcomes through institutional mandates and harmonised land-use planning.

Codifying Nature-Based Solutions (NBS) in the National Environmental Action Programme (NEAP)

The National Environmental Action Programme (NEAP) serves as Georgia's primary vehicle for addressing climate change adaptation, disaster risk reduction, and land degradation. Traditionally, state responses to environmental hazards such as seasonal flooding in the Alazani Valley or landslides in mountainous regions have relied heavily on "grey infrastructure" (e.g., concrete river embankments and artificial retaining walls), which often incurs high capital costs and unintended ecological disruption.

Codifying Nature-Based Solutions (NBS) within the NEAP provides a more resilient, cost-effective, and multifunctional alternative. By leveraging natural ecosystem processes, national strategies can prioritise initiatives such as the restoration of riparian floodplains along the Alazani River, eco-engineering for slope stabilisation, and urban green infrastructure development. This structural shift ensures that infrastructural investments simultaneously support climate resilience, protect local biodiversity, and deliver critical socio-economic co-benefits to surrounding communities.

Strengthening Environmental Justice (EJ) through the Aarhus Convention Framework

As a signatory to the Aarhus Convention, Georgia possesses a foundational legal infrastructure for environmental democracy, which theoretically guarantees public access to information, justice, and participation in decision-making. In practice, however, procedural mechanisms often function as formalistic or administrative hurdles, failing to achieve meaningful stakeholder engagement.

Applying the multidimensional lens of Environmental Justice (EJ) can significantly bridge the gap between formal legal frameworks and local realities. For instance, when establishing new geoparks or implementing regional climate adaptation strategies, state institutions should move beyond formal compliance and actively incorporate:

* Procedural Justice: By establishing transparent, bottom-up consultative channels that give a decisive voice to local populations.
* Recognition Justice: By explicitly acknowledging and safeguarding the cultural identities, traditional land-use rights, and specific socio-economic vulnerabilities of local agrarian and mountain communities.

This dual focus guarantees that the benefits of green development are equitably distributed (Distributional Justice), thereby mitigating the risk of green gentrification or community displacement.

Conclusion

This study examined the development and significance of three major paradigms of current environmental governance: nature-positive policies (NP), environmental justice (EJ), and nature-based solutions (NBS) and discussed their potential embedding into Georgia’s national environmental policy. Each approach reflects a transition from traditional reactive environmental management toward proactive strategies that integrate ecological restoration, social equity, and sustainable development.

Nature-positive policies contribute not only to reducing environmental degradation but also to actively restoring ecosystems and promoting sustainable interactions between society and nature. Environmental justice emphasises the equitable distribution of environmental benefits and burdens, inclusive decision-making, and the recognition of vulnerable communities. Nature-based solutions provide practical mechanisms for implementing these principles by using ecosystem functions to address climate change, biodiversity loss, and socio-economic challenges simultaneously. Collectively, these paradigms establish a multidimensional governance framework that connects environmental, social, and economic objectives.

In Georgia, the incorporation of NP, EJ, and NBS approaches has the potential to significantly improve the management of geoparks, protected areas, biodiversity conservation initiatives, and climate-sensitive regions such as Kakheti, Kvemo Kartli, and Javakheti. Achieving these objectives requires strengthening institutional capacity, improving ecological and socio-economic data collection, establishing participatory governance mechanisms, and ensuring long-term financial support. Equally important is the adaptation of international environmental approaches to Georgia's specific socio-cultural, geographical, and ecological conditions in order to produce meaningful environmental and social outcomes rather than symbolic policy implementation.

The study further demonstrates that the incorporation of emerging ecopolitical paradigms into Georgian environmental governance may strengthen ecosystem resilience, increase public participation, and improve alignment with international environmental standards and sustainability strategies. By translating global environmental concepts into local governance practices, Georgia has the opportunity to advance sustainable regional development while addressing climate risks, protecting biodiversity, and promoting social equity.

Ultimately, the successful implementation of these approaches depends on a holistic, interdisciplinary, and inclusive governance model that effectively connects international environmental concepts with local realities and ensures that environmental governance benefits both ecosystems and society.

Competing interests

The author declares that they have no competing interests.

ORCID iD

Tamar Chichinadze *https://orcid.org/0000-0003-3741-3485*

References

Agyeman, J., Schlosberg, D., Craven, L., & Matthews, C. (2016). Trends and directions in environmental justice: From inequity to everyday life, community, and just sustainabilities. Annual Review of Environment and Resources, 41(1), 321–340. https://doi.org/10.1146/annurev-environ-110615-090052

Bullard, R. D. (1990). Dumping in Dixie: Race, class, and environmental quality. Westview Press.

Chichinadze, T., & Tsiklauri, K. (2025). Protected areas policy and geopolitics in Georgia: Convergence of ecological governance and spatial strategy. Georgian Geographical Journal, 5(3), 79–85. https://doi.org/10.52340/ggj.2025.05.03.09

Cohen-Shacham, E., Walters, G., Janzen, C., & Maginnis, S. (Eds.). (2016). Nature-based solutions to address global societal challenges. International Union for Conservation of Nature. https://doi.org/10.2305/IUCN.CH.2016.13.en

Convention on Biological Diversity. (2023). Kunming–Montreal Global Biodiversity Framework. https://www.cbd.int/gbf

Eggermont, H., Balian, E., Azevedo, J. M. N., Beumer, V., Brodin, T., Claudet, J., Fady, B., Grube, M., Keune, H., Lamarque, P., Reuter, K., Smith, M., van Ham, C., Weisser, W. W., & Le Roux, X. (2015). Nature-based solutions: New influence for environmental management and research in Europe. GAIA, 24(4), 243–248. https://doi.org/10.14512/gaia.24.4.9

European Commission. (2019). Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Review of progress on implementation of the EU green infrastructure strategy (COM(2019) 236 final). Publications Office of the European Union.

IUCN (2020). Global Standard for Nature-based Solutions. A user-friendly framework for the verification, design and scaling up of NbS. First edition. Gland, Switzerland: IUCN.

Kabisch, N., Korn, H., Stadler, J., & Bonn, A. (Eds.). (2017). Nature-based solutions to climate change adaptation in urban areas. Springer. https://doi.org/10.1007/978-3-319-56091-5

Ministry of Environmental Protection and Agriculture of Georgia. (2014). National biodiversity strategy and action plan of Georgia 2014–2020. Government of Georgia.

Ministry of Environmental Protection and Agriculture of Georgia. (2018). Third national environmental action programme of Georgia (NEAP-3) 2017–2021. Government of Georgia.

Pellow, D. N. (2018). What is critical environmental justice? Polity Press.

Schlosberg, D. (2007). Defining environmental justice: Theories, movements, and nature. Oxford University Press.

Schlosberg, D. (2013). Theorising environmental justice: The expanding sphere of a discourse. Environmental Politics, 22(1), 37–55. https://doi.org/10.1080/09644016.2013.755387

United Nations Economic Commission for Europe. (2014). The Aarhus Convention: An implementation guide (2nd ed.). United Nations.

United Nations Environment Programme. (2021). Adapting with nature: Making economies and societies resilient through nature-based solutions.

The Role of the Chemical Industry (Green Chemistry) in Sustainable Development and the Green Economy

Zaur Imrani[1,*], Yusif Hidayatli[1], Murad Tofigzade[1]

[1] Institute of Geography, Baku, Azerbaijan

* Corresponding author: zaur_imrani@mail.ru

Georgian Geographical Journal, 2026, 6(1) 75-79

DOI:
https://journals.4science.ge/index.php/GGJ

Citation: Imrani, Z.; Hidayatli, Y.; Tofigzade, M. The Role of the Chemical Industry (Green Chemistry) in Sustainable Development and the Green Economy. *Georgian Geographical Journal* 2026, 6(1), 75-79. https://doi.org/10.52340/ggj.2026.06.01.10

Abstract

The chemical industry processes natural and synthetic raw materials, altering their properties and creating new substances. The chemical industry, which produces goods for various sectors of the economy, also ensures the sustainability of production. In the context of sustainable development and a green economy, the chemical industry not only produces economically efficient and socially responsible products but also operates in an environmentally friendly manner without harming human health. In Azerbaijan, the chemical industry is represented in the fields of petrochemicals (synthetic rubbers, synthetic fibres, plastics, etc.), basic chemicals (acids, alkalis, mineral fertilisers, etc.), pharmaceuticals (medicinal preparations, biochemical products, etc.), and household chemicals (detergents, cleaners, cosmetic products, etc.). However, these fields are almost not working at their full capacity, and their activity is based on imported products. Furthermore, the chemical industry can, in some cases (technical accidents, negligence during the production process, outdated technology, etc.), cause harm to the environment and its components. In such a context, the implementation of green chemistry, as practised in leading countries of the world, is being emphasised, aligning with the demands of the modern era. This is because green chemistry minimises environmental impact and is characterised by its technological innovations. It is precisely in this context that the present article discusses the advantages of green chemistry.

Keywords: green economy, sustainable development, chemical industry, green chemical industry, natural and synthetic raw materials, extraction, processing

Introduction

In the modern era, the chemical industry plays an essential role across nearly all sectors of modern society, including extraction and processing industries, agriculture, services, and other sectors. As a result, these activities contribute to the depletion of natural resources and environmental pollution due to industrial waste. From this perspective, the chemical industry requires new and innovative approaches, which can be addressed through the green chemistry approach. Given that the chemical industry spans all sectors of human activity, it is increasingly important for tackling global challenges and safeguarding the welfare of future generations. This entails preventing the depletion of natural resources, ensuring sustainable environmental management, eliminating hazardous production processes, minimising waste to zero through technological innovations in consumption, discontinuing the use of harmful synthetic chemicals in agriculture, and applying biotechnology in the processing of agricultural products (Figovsky & Gumerov, 2019). In this process, the organization of production, consumption, and management is made possible through the application of green chemistry. This is because green chemistry is considered a specialised field that implements policies aimed at reducing greenhouse gas and other toxic emissions, while also supporting the rational use of alternative energy sources.

Sustainable Development and green chemistry

In 2015, the United Nations (UN) summit identified 17 Sustainable Development Goals for the period up to 2030. A significant portion of them (6. Clean Water and Sanitation, 9. Industry, Innovation, and Infrastructure, 12. Responsible Consumption and Production, 13. Combating Climate Change, 14. Life Below Water, 15. Protection of land ecosystems) can be linked to the development and modernization of the chemical industry. This also allows green chemistry in the chemical industry to be characterized not only as a new philosophy of chemistry and chemical technology but also as an effective tool for sustainable development (Atlaskin et al., 2024). However, at the 4th session of the UN Environment Assembly held in Nairobi in March 2019, the report titled "Global Chemicals Outlook II: Innovative Solutions for Environmental Challenges and Sustainable Consumption and Production" concluded that the global target to minimize the adverse impacts of chemicals and waste would not be achieved by 2020 (UNEP, 2019). In such a context, it should not be overlooked that modern science is increasingly focusing on sustainable development and the green chemical industry. Green chemistry seeks to ensure that production processes are safe, resource-efficient, and generate minimal waste.

The present analysis indicates that that the chemical industry, and particularly green chemistry, plays a crucial role in achieving the Sustainable Development Goals. These can be summarized in the following three aspects:

1) Cognitive Chemistry – the development of science and educational processes;
2) Industrial Chemistry – technologically innovative approaches and their application;
3) Environmental Chemistry – efficient use of natural resources and the transition to waste-free technologies.

The Role of the Chemical (Green Chemistry) Industry in the Economic System

The chemical industry involves the processing of hydrocarbons, minerals, and other raw materials. The primary objective of the chemical industry is the efficient use of natural resources. This strategic goal encompasses not only extraction but also advanced processing using the latest technologies, enabling the production of high-quality products that are in strong demand in both domestic and international markets (Gurbanmyradova et al., 2025). Green chemistry refers to the design and implementation of processes for the production of chemical products that do not generate toxic waste and that incorporate continuously improved, innovative technologies, thereby minimizing adverse impacts on human health and the environment. This industrial sector aims to mitigate environmental impacts through the development of alternative and safer technologies (Saleh & Koller, 2018). One of the criteria used in the evaluation of technological processes is the principle of chemical reaction efficiency. In this context, the concept of waste-free production is emphasized, or, where waste generation is unavoidable, ensuring that it is non-hazardous (Sheldon, 1992). As a result, several approaches have been proposed to enable the near-complete utilization of renewable raw materials, which has had a significant impact on fields such as chemical metallurgy, construction, advanced materials, medical biology, pharmaceuticals, and the generation of alternative energy (Dyukarev et al., 2012). This approach accelerates the transition toward sustainable development and a green economy. In this context, a green economy is understood as the achievement of economic growth with minimal environmental impact, promoting the efficient use of natural resources. The transition to a green economy is widely recognized as a primary pathway for addressing global environmental challenges.

In Azerbaijan, the chemical industry is primarily based on a raw material foundation comprising oil and natural gas, sulfur pyrite, alunite, oilfield waters, rock salt, and other resources. These resources include iodine–bromine waters located in Neftchala, Xıllı, Babazenen, Mushovdagh, Maghan, and Shirvan; the Boyukshor and Masazır lakes on the Absheron Peninsula, as well as sedimentary salt deposits in the Gobustan region; barite deposits at the Bashlıqlar (reserves of 133 thousand tons) and Chovdar (reserves of 68 thousand tons) sites in the Goygol district; sulfur pyrite occurrences in the Toraghanlı area of the Balaken district and the Chıraqdere area of the Gadabay district; copal deposits in the villages of Qurchu and Yukharı Agach in the Lachın district; and rock salt deposits in Nakhchivan (with reserves of approximately 1.3 billion tons), among others (Imrani et al., 2014). Currently, the chemical and petrochemical industry in Azerbaijan is considered one of the most significant components and a driving force of the national economy. This industrial sector provides a foundation for socio-economic development and plays a significant role on the sectoral and regional structure of the economy.

The development of the chemical industry in Azerbaijan has been closely linked to the oil and gas sector and is reflected in the "Strategic Roadmap for the Development of the Oil and Gas Industry (including Chemical Products)" (President of the Republic of Azerbaijan, 2016). As a strategic goal, the establishment of several new large-scale chemical industry enterprises and their diversification has become a strategic development priority. For example, the heavy industry enterprises in Sumgayıt, which have been in operation since 1945—including chemical, pipe-rolling, synthetic rubber, aluminium, and superphosphate plants—were reorganized on December 21, 2011, as the Sumgait Chemical Industrial Park, established on a 167.66-hectare site within the territory of the "Azerikimya" Production Association (Azerbaijan State News Agency, 2011). Currently, the area of the Sumgait Chemical Industrial Park has been expanded to 508.14 hectares. According to the most recent report, the total investments in the industrial park amount to 2.1 billion USD, with 23 resident companies and a workforce of 10,000 employees (Suleymanli, 2021). The efforts undertaken aim to increase the production capacity of competitive, high-quality, and export-oriented chemical industry products, as well as to establish the manufacture of green chemistry products within the industrial park.

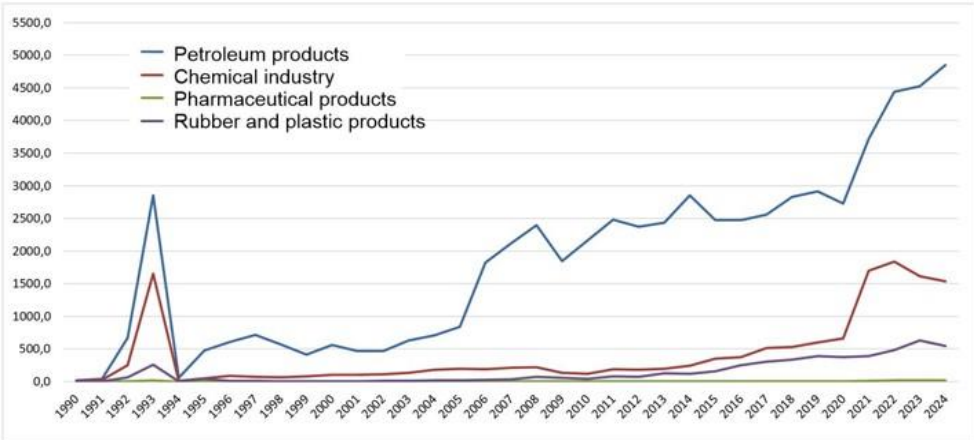


Figure 4. Volume of products produced by enterprises related to the chemical industry, million manats. Source: Azerbaijani Industry. Baku, 2025.

An examination of the statistics on the number of industrial enterprises in Azerbaijan and the volume of their production reveals a pronounced trend of growth between 1994 and 2024. Specifically, while the volume of industrial products produced amounted to 224 million manats in 1994, this figure is projected to increase to 64.9 billion manats by 2024 (Budagov, 2025). The production capacity of enterprises related to the chemical industry increased from 33.4 million manats to 6.9 billion manats over the corresponding years (fig. 1). These data indicate that those enterprises related to the chemical industry-including oil, pharmaceutical, and rubber and plastic products—are expected to account for 10.7% of total industrial production in 2024, with chemical industry enterprises alone representing just 2.4% of this figure.

An analysis of the most recent five years, from 2020 to 2024, shows that the number of enterprises related to the chemical industry increased by 228 units, reaching a total of 511. Of these, 51.3% are state-owned enterprises, while 48.7% are non-state enterprises. However, in the overall structure of industrial enterprises (fig. 2), this indicator is not as prominently reflected. Specifically, while the share of enterprises related to the chemical industry in the overall structure of industrial enterprises was 10.1% in 2020, it increased slightly to 10.7% by 2024 (Azerbaijan State News Agency, 2011). These developments further highlight the potential for advancing the chemical industry in the country at a new pace. This is because the chemical industry continues to evolve through technological innovation, resulting in environmental protection and sustainable ecological benefits. This can be clearly observed in the case of the Sumgait Chemical Industrial Park.

In Azerbaijan, the chemical industry should leverage the advantages of green chemistry and its applications, as is done in developed countries, to achieve sustainable development and a green economy. Green chemistry is primarily applied in the pharmaceutical and organic chemical industries using modern technologies. This factor also affects both the quality of the products produced and their export orientation.

Conclusion

Green chemistry is characterized by engineering processes that emphasize by low energy consumption, high efficiency and cost-effectiveness, and minimal waste generation, aiming to achieve economic benefits in production while adhering to the principles of sustainable development. From this perspective, the implementation of green chemistry in Azerbaijan is particularly important. This is because green chemistry contributes to the modernization of industrial production and achieve environmentally sustainable industrial development. In Azerbaijan, the chemical industry is primarily based on the production of oil and gas products and is considered the largest industrial consumer. During such processes, harmful waste is generated, which green chemistry seeks to reduce through the adoption of innovative, technology-driven solutions. In this context, green chemistry aims to minimize potential harm in the production of oil, pharmaceutical, and rubber and plastic products-and it is has demonstrated considerable potential in achieving this objective.

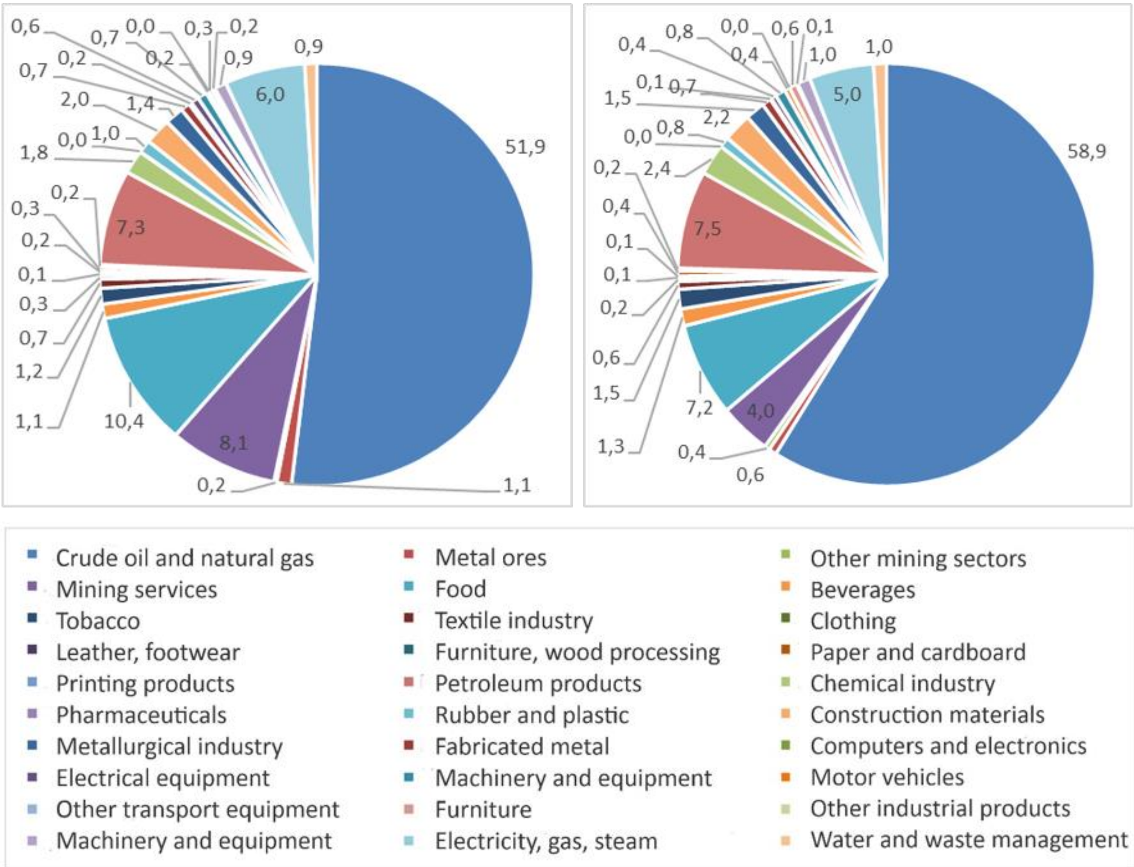


Figure 5. Structure of industrial enterprises, %. Source: Azerbaijani Industry. Baku, 2025

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

All authors provided critical feedback and helped shape the research, analysis and manuscript.

ORCID iD

Zaur Imrani https://orcid.org/0000-0002-0606-3753
Yusif Hidayatli https://orcid.org/0009-0001-0173-3156
Murad Tofigzade https://orcid.org/0009-0002-1550-6584

References

Atlaskin, A. A., Atlaskina, M. E., Vorotyntsev, A. V., Grebennikova, M. V., Zheleznova, I. V., & Kholkin, E. G. (2024). Зелёная химия как инструмент устойчивого развития [Green chemistry as a tool for sustainable development]. V. I. Vernadsky Non-Governmental Environmental Foundation. https://vernadsky.ru/assets/files/1/977/Зелёная%20химия%20как%20инструмент%20устойчивого%20развития.pdf

Azerbaijan State News Agency. (2011, December 21). President decrees on establishment of Sumgayit Chemical Industrial Park. https://azertag.az/en/xeber/president_decrees_on_establishment_of_sumgait_chemical_industrial_park-219048

Budagov, T. (Ed.). (2025). Azerbaijan industry (Statistical collection). Narinci. (Original work published in Azerbaijani)

Dyukarev, V. A., Kocharov, S. A., & Khodyrev, V. I. (2012). Green chemistry: Application of renewable resources in chemical processes (Project approach). Fine Chemical Technologies, 7(3), 77–89. (In Russian)

Figovsky, O., & Gumerov, V. (2019, April 9). Зелёные технологии [Green technologies]. S. P. Kurdyumov Synergetics Website. https://spkurdyumov.ru/economy/zelyonye-texnologii/

Gurbanmyradova, A., Sar'yeva, O., & Amanjaeva, S. (2025). Chemical industry. Modern Innovations, 2(48), 8–10. (In Russian)

Imrani, Z. T., & Zeynalova, K. Z. (2014). Economic and geographical features of the territorial organization of the economy in Azerbaijan. Nafta-Press. (In Azerbaijani)

Saleh, H. E.-D. M., & Koller, M. (2018). Introductory Chapter: Principles of Green Chemistry. In Green Chemistry. InTech. https://doi.org/10.5772/intechopen.71191

Sheldon, R. A. (1992). Organic synthesis—Past, present and future. Chemistry and Industry, (23), 903–906.

Suleymanli, O. (2021). Economic and legal mechanisms of innovative management of Azerbaijani industrial parks. Silk Road, (2), 97–103. (In Azerbaijani)

President of the Republic of Azerbaijan. (2016, December 6). Strategic roadmap for the development of the oil and gas industry (including chemical products) of the Republic of Azerbaijan (Presidential Decree No. 1138). Office of the President of the Republic of Azerbaijan. https://policy.asiapacificenergy.org/sites/default/files/Strategic%20Road%20Map%20for%20the%20development%20of%20oil%20and%20gas%20industry%20%28Decree%20No.%201138%20of%202016%29%20%28AZ%29.pdf

United Nations Environment Assembly of the United Nations Environment Programme. (2019). Global chemicals outlook II: Summary for policymakers (UNEP/EA.4/21). United Nations Environment Programme.